# Fuel Cell Technology Benefits for Selected Industries

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**Prepared for:**
**U.S. Department of Energy**

**and**

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# List of Exhibits

# List of Acronyms

| | |
|---|---|
| AC | Alternating Current |
| ADG | Anaerobic Digester Gas |
| AEO | Annual Energy Outlook |
| BOD | Biochemical Oxygen Demand |
| Btu | British Thermal Units |
| < C | Degree Celsius |
| CBECS | Commercial Buildings Energy Consumption Survey |
| CBP | County Business Patterns |
| $CH_4$ | Methane |
| CO | Carbon monoxide |
| $CO_2$ | Carbon dioxide |
| CWNS | Clean Water Needs Survey |
| DG | Distributed Generation |
| DoD | Department of Defense |
| DOE | Department of Energy |
| EIA | Energy Information Agency |
| EPA | Environmental Protection Agency |
| < F | Degree Fahrenheit |
| $ft^3$ | Cubic Foot |
| g/kWh | Grams/Kilowatt hour |
| GW | Gigawatt |
| GWh | Gigawatt hour |
| $H_2$ | Hydrogen |
| $H_2S$ | Hydrogen Sulfide |
| $H_3PO_4$ | Phosphoric Acid |
| HHV | Higher Heating Value |
| Hz | Hertz |
| kW | Kilowatt |
| $kW/ft^3$ | Kilowatt/per Cubic Foot |
| kWh | Kilowatt hour |
| lbs./hr | Pounds/hour |
| lbs./yr | Pounds/year |
| LCA | Life Cycle Assessment |
| LHV | Lower Heating Value |
| MEA | Membrane/electrode assembly |
| MCFC | Molten Carbonate Fuel Cell |
| MGD | Million Gallons/Day |
| MW | Megawatt |
| MWh | Megawatt hour |
| NAICS | North American Industry Classification System |

| | |
|---|---|
| NETL | National Energy Technology Laboratory |
| $NO_x$ | Nitrogen oxides |
| O & M | Operation and Maintenance |
| O | Oxide Ions |
| PEM | Proton Exchange Membrane |
| PAFC | Phosphoric Acid Fuel Cell |
| POTWs | Publicly Owned and Operated Wastewater Treatment Works |
| ppm | Parts Per Million |
| ppmv | Parts Per Million Volume |
| Pt | Platinum |
| Q&A | Question & Answer |
| R&D | Research & Development |
| scf. | Standard Cubic Feet |
| SOFC | Solid Oxide Fuel Cell |
| $SO_2$ | Sulfur dioxide |
| SSOs | Sanitary Sewer Overflows |
| $/kW | Dollars/Kilowatt |
| ¢/kWh | Cents/Kilowatt hour |
| V | Volts |
| vol% | volume percent |
| WWTPs | Wastewater Treatment Plants |
| yr. | Year |

# Executive Summary

## Objective

This report summarizes work conducted on behalf of the National Energy Technology Laboratory's (NETL) Fuel Cell program. The NETL Fuel Cell program provides support for research and development of efficient and economical fuel cells for stationary power generating applications. For this industry sector benefits study, NETL has partnered with, U.S. DOE's Office of Energy Efficiency and Renewable Energy, Biopower Program and the U.S. Environmental Protection Agency (EPA) to define the benefits, environmental and other, for stationary fuel cells in 2001 and 2010 using biogas (i.e., waste methane) or natural gas.

## Background

The Energy Information Administration (EIA) is forecasting an unprecedented demand for energy in the next 20 years. At the same time, public policy is demanding efficiency and environmental performance in the expansion of energy generating capacity. Fuel cell technology, a distributed generation (DG) infrastructure, inherently provides many of these desired benefits.

## Industry Sectors Profiled

Fuel cell opportunities were profiled for a group of industry sectors chosen by the NETL and EPA based upon existing industry sector interest and perceived potential benefits from fuel cells. For each industry sector, a profile was developed to characterize the number of establishments comprising the sector, electricity usage and cost, thermal usage, biogas/methane production, current energy-related environmental releases, and fuel cell unit size compatibility. These industry sectors were prioritized (first, second, or third tier) to indicate those best suited to benefit widely from fuel cell technology by 2010. Benefits were noted for each first tier industry sector in terms of implementing one or all of the four leading stationary fuel cell technologies (i.e., phosphoric acid, proton exchange membrane, solid oxide, and molten carbonate). See Exhibit ES-1 for a list of the factors used for defining the benefits of each particular fuel cell technology in each down-selected industry sector. These benefit analyses were summarized in terms of energy savings (including deferred fossil fuel consumption), financial costs/savings, and reduced pollutant emissions anticipated within each industry sector from the adoption of fuel cells. Benefits anticipated for 2010 are noted in this Executive Summary. Additional calculations estimating the benefits for the current year (2001) are referenced in the Final Report. Data for 2001 were gathered from existing databases then revised for 2010 based on calculated growth rates for each sector.

**Industry Sectors Profiled**

First Tier
Agriculture-Livestock
Educational Services
Hospitals
Telecommunications Support
Wastewater Treatment Plants

Second Tier
Banking Facilities
Computer/Data Facilities
Landfills
Military Bases
Traveler Accommodations

Third Tier
Logging
Paper Manufacturing

**EXHIBIT ES-1: BENEFIT FACTORS FOR THE EVALUATION OF FUEL CELL TECHNOLOGY**

| | | | |
|---|---|---|---|
| **TECHNICAL** | | | |
| • Technology maturity<br>• Responsiveness<br>• Fuel flexibility<br>• Start-up time | • Physical space requirements<br>• Co-generation options<br>• Fuel efficiency | • Infrastructure requirements<br>• Quality of power produced | • Ease of operation<br>• Output reliability/consistency |
| **ECONOMIC** | | | |
| • Acquisition costs (purchase and installation)<br>• Service life<br>• Emissions credits | • Annual operation and maintenance costs<br>• Annual revenue from sale of output | • Annual business energy tax credits/rebates (Federal, State, local)<br>• End-of-Life value/cost | • Other annual indirect costs (e.g., liability, environmental)<br>• Lead time |
| **ENVIRONMENTAL** | | | |
| • Air emissions<br>• Life-Cycle related benefits | • Wastewater release | • Solid waste (non-hazardous & hazardous) | • Resource usage (water, fuel feedstock) |
| **INSTITUTIONAL** | | | |
| • Regulatory barriers | • Mgmt/customer acceptance | • Staff expertise/training required | |

## Findings: Energy Savings Benefit

Fuel cells offer a reliable, premium power supply with potentially increased efficiency through co-generation and/or the avoidance of line losses. Operating on natural gas also reduces the quantity of other fossil fuels (coal, oil) that are needed for energy production. In addition, industries that generate a high heat content by-product (e.g., biogas) can use fuel cells to convert this often underutilized resource into an inexpensive energy source. Exhibit ES-2 summarizes the electricity usage and anticipated coal and oil savings assuming that fuel cells are fully implemented throughout the industry sectors (i.e., 100% market penetration). For the five industry sectors below, natural gas consumption would increase to 1,785,071 million cubic feet and fuel cells would utilize of 3,317,783 million cubic feet of biogas.

**EXHIBIT ES-2: FUELS CONSERVED BY USING FUEL CELLS IN 2010**

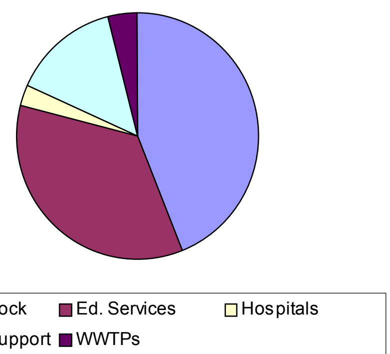
| INDUSTRY SECTOR | ELECTRICITY CONSUMPTION (MWh/yr.) | COAL DISPLACED (million lbs.) | OIL DISPLACED (million gal.) |
|---|---|---|---|
| Agriculture - Livestock Facilities | 91,043,383 | 40,145 | 286 |
| Educational Services (e.g., schools) | 34,433,704 | 15,183 | 108.1 |
| Hospitals | 46,834,143 | 20,651 | 147.1 |
| Telecommunications Support Facilities | 26,628,501 | 11,742 | 83.7 |
| Wastewater Treatment Plants (WWTPs) | 8,096,560 | 3,570 | 25.4 |
| **TOTAL** | 207,036,291 | 91,291 | 650.3 |

## Findings: Cost Savings Benefit

The financial decision of an industry sector whether to replace or augment their existing power supply with fuel cells will likely include a review of the installed costs and a comparison of operating costs (including fuel costs). Installed costs, while high today (ranging from $2,500-$8,000 per kW, with some additional offset from buy-down grant programs) as would be expected with an emerging technology, are predicted to drop dramatically by 2010 (to between $875 and $1250 per kW) as next generation technologies are implemented. Over the same period, fuel cell operating costs are also anticipated to reduce substantially as maintenance intervals lengthen and procedures become more rudimentary (estimated at 1¢/kWh in 2010). Exhibit ES-3 summarizes the anticipated electricity cost savings from implementing fuel cell technology given the specific cost parameters within each industry sector and assuming that fuel cells are fully implemented.

**EXHIBIT ES-3: COST SAVINGS FROM FUEL CELL IMPLEMENTATION IN 2010**

| INDUSTRY SECTOR | MARKET POTENTIAL (NUMBER OF ESTABLISHMENTS)[1] | ANTICIPATED COST SAVINGS[2] (¢/kWh) | |
|---|---|---|---|
| Agriculture - Livestock | 192,616 | 0.8 | |
| Educational Services | 49,282 | 1.8 | |
| Hospitals | 7,317 | 0.1 | |
| Telecommunications Support | 20,108 | 0.9 | |
| WWTPs | 4,077 | 0.8 | |
| **TOTAL** | 273,400 | n/a | $1.66 Billion |




Note: 1. Compatible with anticipated fuel cell unit sizes available in 2010 (25 kW to 25 MW)
2. Compared to the average cost per kWh for electrical power from the national energy grid. Specific costs per kWh varies by industry. 2001 costs were used EIA.

## Findings: Pollution Avoided Benefit

Efficiency gains and the potential for renewable resource use combine to make fuel cell technology almost pollution free during operation. In terms of upstream manufacturing operations, the construction of fuel cells involves common industrial activities that are not expected to produce inordinate or unusual waste streams, but will involve the mining of rare earth catalysts. Downstream end-of-life impacts are less defined with manufacturers estimating that 95% of the fuel cell's materials can be recycled, that 5% will be landfilled, and that less than one percent will be disposed as hazardous waste (containing heavy metals and/or corrosive fluids). Because these life cycle impacts are less defined, this analysis focused on the reduction in grid-related emissions in each industry sector if fuel cells fully replaced existing grid-power sources (see Exhibit ES-4).

**EXHIBIT ES-4: REDUCED POLLUTANT EMISSIONS FROM FUEL CELL IMPLEMENTATION IN 2010**

| INDUSTRY SECTOR | POLLUTION AVOIDED (million lbs.) | $CO_2$ avoided (million lbs.) | $SO_2$ avoided (million lbs.) | $NO_x$ AVOIDED (million lbs.) |
|---|---|---|---|---|
| Agriculture - Livestock | 36,978 | 36,693 | 192 | 93 |
| Educational Services (e.g., schools) | 13,986 | 13,878 | 72 | 36 |
| Hospitals | 18,843 | 18,698 | 98 | 47 |
| Telecommunications Support | 10,815 | 10,731 | 56 | 28 |
| Wastewater Treatment Plants | 3,282 | 3,256 | 17 | 9 |
| **TOTAL** | 83,904 | 83,256 | 435 | 213 |

## Conclusions

As this study identified, fuel cell commercialization presents many benefits compared to a baseline power source (e.g., grid power) including financial savings, reduced fossil fuel reliance, and reduced pollutant emissions (including greenhouse gases). In addition, for those industry sectors that generate biogas (e.g., wastewater treatment plants, landfills, and certain agricultural or wood processing facilities), a switch to fuel cells can make efficient use of this often underutilized resource. Collectively assuming full market penetration (for the Tier 1 sectors), the identified benefits for 2010 would equate to:

- the avoided annual pollution from over 200 typical 100 MW power plants
- avoided coal usage equivalent to one-tenth the annual coal production of Wyoming, the largest coal producing state
- potential financial savings equal to 8% of their purchased electricity cost ($1.6 billion savings compared to estimated cost of $19.9 billion)

Furthermore, as fuel cell technology matures and the fuel cell manufacturing industry reduces capital costs and operation and maintenance (O&M) costs, a broader spectrum of applications will emerge.

## Next Steps

There are quantifiable benefits from utilizing stationary fuel cell technologies within the industry sectors studied. This enthusiasm should be tempered by noting that the performance and cost values for 2010 reflect the attainment of aggressive targets for efficiency improvements and economy-of-scale projections. Appropriate next steps fall into two categories: (1) helping to prepare the market by reducing potential barriers to entry and (2) refining the market profile analysis.

### Reduce Potential Barriers to Entry

- ***Partner with Targeted Industry Sectors.*** Activities can include targeted outreach campaigns, pilot tests, and workgroups to refine performance requirements.
- ***Quantify Comparative Life Cycle Environmental and Cost Benefits.*** Document via a comparative life cycle assessment (LCA) and life cycle costing of fuel cell technologies. Develop a web-based tool to allow facilities to calculate their own savings.
- ***Inventory Past and Present Fuel Cell Implementations.*** Generate a database with economic, environmental, and technical data to provide insight from past experiences.
- ***Address O&M Complexity Concerns.*** Overcome reluctance among industry sectors for which energy generation processes are not their main focus (e.g., hospitals, telecommunications support facilities, etc.) through education at all levels, including managers and current staff, as well as in training future workers (e.g., curriculum development).

### Refine Market Profile Analysis

- ***Continue to Refine/Expand Market Profiles.*** This study examined only the first tier of profiled industry sectors. The seven industry sectors in the second and third tiers represent additional market opportunities which should be explored. In addition, this study is a snapshot in time for a rapidly evolving industry. As such, the market profiles must be revisited regularly as the technology matures and as better resolution is obtained on anticipated life cycle benefits and impacts.

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# 1.0 Introduction

## 1.1 Background

In its *Annual Energy Outlook 2001* (AEO 2001), the U.S. Department of Energy's (DOE), Energy Information Administration (EIA) projects that by 2020 (assuming a baseline of 1999), the U.S. will require 393 gigawatts (GW) of additional electrical generation capacity (excluding cogeneration) to meet the nation's demand for electricity. EIA also projects that by 2020 distributed generation (DG), "the use of small scale power generation technologies located close to the load being served," will become an increasingly popular approach to meeting the demands for additional capacity in selected industry sectors. For example, EIA projects that in the building sector, DG will increase by 56% by 2020 to produce 0.4% of the total electricity supply to that sector. Distributed generation is beneficial to electrical utilities because it adds capacity incrementally, and for electricity customers, it provides a reliable source of electricity onsite.

As demand for additional electricity capacity increases, DOE and others are looking to fuel cells as a promising new technology for electricity production. In addition to electricity, fuel cells can produce heat and hot water with high efficiency, and generate exceptionally low emissions. Fuel cells can be more efficient than combustion technologies, reduce air pollution and greenhouse gases, provide distributed power generation which reduces transmission losses, and can be used for cogeneration of heat and power. A commercially-available phosphoric acid fuel cell (PAFC) rated at 200 kilowatts (kW) is already in use. In addition, (stationary applications) fuel cells are currently being developed and pilot tested using proton exchange membrane (PEM), molten carbonate fuel cell (MCFC), and solid oxide fuel cell (SOFC) technologies. These fuel cells are or will be available for use in residential, commercial, and industrial applications.

Most fuel cells are capable of operating on biogas or natural gas. Biogas is available at wastewater treatment plants, landfills, and certain agricultural and wood processing facilities. Currently, much of the biogas generated is vented or flared due to the additional capital costs and operation and maintenance expenses of gas cleanup and power generation equipment. Fuel cells can make efficient use of this wasted or under-utilized biogas resource while overcoming the current financial limitations of other options.[1]

Natural gas is the fuel of choice for fuel cells operated for onsite, premium, or backup power in applications including hospitals, military bases, computer/data and banking facilities,

[1] Based on year 2010 economic feasibility assessment; see economic assessment sections included in the industry-specific chapters.

telecommunications support and Internet datacenters. Many of these fuel cell DG applications can utilize the heat/thermal energy produced by the fuel cell for added efficiency at the site.

DOE is working with fuel cell manufacturers to develop reliable and cost-effective fuel cells. However, DOE understands that a major determining factor in the penetration of these fuel cells to residential, commercial, and industrial markets and their applications will be the public perception of fuel cell benefits. In support of its ongoing fuel cell research and development (R&D) program, DOE is interested in identifying and quantifying the benefits of fuel cells used in stationary applications with biogas and/or natural gas. This information can be used by DOE and fuel cell developers to communicate the availability and advantages of fuel cells and their applications to potential users/markets.

Similarly, the U.S. Environmental Protection Agency (EPA) is interested in quantifying potential environmental benefits of fuel cells, in commercial/industrial applications, particularly for use at publicly owned and operated wastewater treatment works (POTWs). EPA requires this information to provide POTWs with the information they need to make appropriate decisions on the potential applications of these new fuel cell technologies. In addition, EPA intends to use this information to identify additional research and demonstration needs to focus the future efforts of potential funding agencies such as DOE. To this end, DOE and EPA have partnered to fund a joint study exploring the potential applications of fuel cell technologies in selected industries. This document is a product of their collaboration.

**Potential Industry Sector Fuel Cell Markets**

- Agriculture-Livestock
- Banking Facilities
- Computer/Data Facilities
- Computer-controlled or Robotic-manufacturing Plants
- Educational Services
- Hospitals
- Industrial Parks
- Landfills
- Logging
- Military Bases
- Paper Manufacturing
- Telecommunications Support
- Traveler Accommodations
- Wastewater Treatment Plants

## 1.2 Objectives

The objectives of this study were to identify and quantify the costs and benefits of fuel cell technologies that operate on either biogas or natural gas for major stationary applications. The study evaluated the potential applications and benefits of fuel cell technologies. These benefits will be quantified in terms of financial savings, energy savings, fossil fuel deferred, and greenhouse gas or pollutant emissions reduced. This investigation was designed to identify the potential markets and opportunities for fuel cells in 14 industrial sectors (See adjacent text box).

## 1.3 Approach

**Methodology Overview**

**Step 1:** Develop market profiles of selected industries
**Step 2**: Compile existing literature on current and future (predicted) fuel cell capabilities
**Step 3**: Identify benefit factors for technology assessment
**Step 4**: Conduct screening and prioritize/evaluate down-selected industry sectors
**Step 5**: Identify and prepare case studies

The approach used to develop this study is divided into five steps that describe the methodology used to collect and analyze cost, and the energy and emissions data needed to identify and prioritize the industry sectors with the greatest potential for utilizing fuel cell technologies. These steps involved collecting data to develop market profiles, reviewing documents to help characterize fuel cell technologies, developing fuel cell benefit factors, and using these data to prioritize and down select candidate industry sectors for likely fuel cell opportunities. An overview of the methodology is included in the adjacent text box and a detailed write-up of this methodology follows.

### 1.3.1 Step 1: Develop market profiles of selected industries

As an initial step, market profiles were developed for each industry sector to characterize the number of establishments or facilities comprising the sector; energy usage in terms of quantity; cost and quality of electricity used; thermal usage, biogas/methane production; and environmental releases. The intent of the market profile was to prepare a preliminary analysis of the potential market for fuel cells in the years 2001 and 2010. This information was used to help identify and prioritize those sectors with the greatest potential for utilizing fuel cell technologies. The market profiles for each industry sector are found in Chapter 2.

### 1.3.2. Step 2: Compile existing literature on current and future (predicted) fuel cell capabilities

Literature searches, bibliography reviews, Internet searches and phone interviews were among the methods used to gather information regarding the available fuel cell technologies for this report. Existing literature and research in the form of articles, reports, and presentations on fuel cell technologies developed by government agencies, non-profit organizations, manufacturers, and private groups were compiled and reviewed. Fuel cell research developed by DOE, the Department of Defense (DoD), EPA, Electric Power Research Institute, and other sources were compiled to assess fuel cell technologies. The research identified four promising fuel cell technologies: PAFC, PEMFC, MCFC, and the SOFC. Information was collected on factors related to fuel cell technology performance, costs, product status and development time frame. These factors provided a standard or baseline against which to measure and compare the various fuel cell technologies. From this information, a detailed list of benefit factors for the fuel cell technologies was developed. The factors provided a measure for determining whether a specific fuel cell technology was feasible or beneficial to be used in each industry sector evaluated. The characterizations of the benefits for each fuel cell type are found in Chapter 3.

### 1.3.3 Step 3: Identify benefit factors for technology assessment

Benefit factors (for 2001 and 2010) were identified in the areas of technical performance, economic performance(e.g. costs and savings), environmental performance, and institutional barriers based on the information compiled under Step 2. These benefit factors were developed as a tool to assess the potential opportunity for using a particular fuel cell technology in each of the selected industries. The benefit factors that were used to evaluate the fuel cell technologies for use in the selected industry sectors are found in Chapter 3.

### 1.3.4 Step 4: Conduct screening and prioritize/evaluate down-selected industry sectors

Using the information on the technologies compiled under Step 2 and an aggregated list of benefit factors (Step 3), a multi-attribute analysis matrix was utilized to array fuel cell technologies against each industry sector characterized under Step 1. The resulting matrix was used to prioritize the industry sectors for further market analysis. Those industries that were judged as the best markets for fuel cells were further evaluated in terms of anticipated benefits. The industry sector analysis is found in Chapter 4. The industry sectors with the highest potential to use fuel cells were judged to be Agriculture-Livestock (Chapter 5), Educational Services (Chapter 6), Hospitals (Chapter 7), Telecommunications Support (Chapter 8), and Wastewater Treatment Plants (Chapter 9). Market evaluations for these sectors are presented in the proceeding chapters. Additional information on the calculations and methodologies used in constructing the analysis are found in Appendices B and C.

### 1.3.5 Step 5: Identify and prepare case studies

A search was conducted to identify and document case studies that illustrate opportunities where fuel cell and competing technologies have been used in the selected applications. Detailed case studies that included data on specific costs and benefits associated with the implementation of a particular fuel cell were developed for inclusion in this report and are found in the accompanying appendices.

# 2.0 Industry Sector Analysis

## 2.1 Market Profile

The purpose of this study is to identify industry sectors where fuel cells may be used as an efficient, environmentally friendly and cost-effective alternative to the traditional electrical power grid. As part of the preliminary analyses of the potential market for fuel cell technologies, market profiles were developed for 14 industry sectors. Each profile includes data regarding the number of establishments or facilities comprising the sector and energy consumption data. Specifically, information on energy consumption in terms of quantity and cost, as well as thermal consumption, biogas production and environmental emissions. A brief discussion on energy demand for each sector is also provided. This information characterizes the electrical and thermal demands and notes any backup system requirements that are specific to the industry.

The data gathered for each industry sector provided the baseline needed to identify and later prioritize those sectors with the greatest potential for utilizing fuel cell technologies. The methodology used to prioritize or "down select" the sectors with the greatest fuel cell technology market potential is presented in Chapter 4.0 of this study. The industrial sectors that were the initial focus of this report are listed alphabetically in Exhibit 2-1 below and discussed in greater detail in the sections that follow.

**EXHIBIT 2-1: LIST OF INDUSTRY SECTORS**

| | |
|---|---|
| Agriculture-Livestock | Landfills |
| Banking Facilities | Logging |
| Computer/Data Facilities | Military Bases |
| Computer-controlled or Robotic-manufacturing Plants[1] | Paper Manufacturing |
| Educational Services[2] | Telecommunications Support |
| Hospitals | Wastewater Treatment Plants (WWTPs) |
| Industrial Parks[1] | Traveler Accommodations[2] |

**Note:**
[1] Industry sector eliminated after further research determined it as too amorphous to define/bound specific fuel cell opportunities.
[2] Industry sector added to initial list after research indicated it as a potential market opportunity for fuel cells.

### 2.1.1 Data and Organization

Each market profile is divided into two sections: Industry Sector Profile and Overview of Energy (Electrical and Thermal) Demand. The first section; Industry Sector Profile, presents the North American Industry Classification System (NAICS) Code for the industry sector, quantifies the number of establishments or facilities comprising the sector, estimates demand and cost, estimates associated environmental emissions from energy generation, and quantifies any onsite biogas production. A summary table that includes these data follows each industry sector discussion. These data represent industry totals for the present year (2001). A detailed breakout for each industry sector by establishment size is presented in Chapter 4.0. A brief description of the data collected for each profile, the data source and unit of measure (if applicable) is presented in Exhibit 2-2. The second section; Overview of Energy (Electrical and Thermal) Demand, describes the base load electricity and thermal demands as well as backup system requirements.

**EXHIBIT 2-2: DATA INDICATORS AND SOURCES**

| MEASURE/INDICATOR | DESCRIPTION | DATA SOURCE | UNIT OF MEASURE |
|---|---|---|---|
| NAICS Code | North American Industry Classification System (NAICS). NAICS is an industry classification system that organizes establishments into industries based on the activities in which they are primarily engaged. | U.S. Office of Management and Budget | Not applicable |
| Number of Establishments | An establishment is a single physical location at which business is conducted or services or industrial operations are performed. The number of establishments represents the sum total of establishments that fall within a specified range nationwide. | U.S. Census Bureau<br>1999 County Business Patterns | Grouped by range, number of employees, by throughput etc. |
| Electricity Cost | Represents the cost of electricity per kWh of power purchased from the grid, averaged over the continental U.S. by industry. | — 1997 Economic Census<br>— Commercial Buildings Energy Consumption Survey (CBECS)<br>— Data sources directly related to the industry sector in question (ex: 1997 Census of Agriculture).<br>— Energy Information Administration (EIA) | cents/Kilowatt-hour (¢/kWh) |
| Total Emissions | Represents the total emissions of $CO_2$, $SO_2$ and $NO_x$ generated when producing the amount of electricity consumed. | Data is derived from electricity consumption data and is calculated from national averages (E-Grid Outlook, EIA) of typical emissions generated from producing electricity. | Million pounds/year (lbs./yr.) |
| Consumption | Represents the total amount of electricity consumed over a year by an industry sector. | Extrapolated from EIA's Commercial Buildings Energy Consumption Survey (CBECS) Data. | Megawatt-hour (MWh) |

**EXHIBIT 2-2: DATA INDICATORS AND SOURCES**

| MEASURE/INDICATOR | DESCRIPTION | DATA SOURCE | UNIT OF MEASURE |
|---|---|---|---|
| Total Thermal Consumption | Represents the total amount of heat or steam consumed over a year by an industry sector. | Extrapolated from EIA's Commercial Buildings Energy Consumption Survey (CBECS) Data. | Megawatt-hour (MWh) |
| Total Biogas Produced | The amount of methane generated as biogas during operation of facilities in WWTP, Agriculture, and Landfill industry sectors. | Applicable only for Agriculture, WWTPs and Landfills, data from the EPA Global Warming Site: National Emissions-Methane Emissions (www.epa.gov/globalwarming/emissions/national/methane.html.<br>— All other data extrapolated from EIA CBECS data. | MetricTon/year |

Data summarizing each industry sector are included in the market profiles that follow.

### 2.1.2 Agriculture-Livestock

Industries involved in raising or fattening animals for sale or for animal products are included in NAICS Code 112: Animal Production. The Animal Production sector includes establishments such as ranches, farms, and feedlots primarily engaged in keeping, grazing, breeding or feeding animals. These animals are kept for the products they produce or for eventual sale. The animals are generally raised in a variety of environments from total confinement or captivity to feeding on an open range pasture. The Animal Production sector is further divided into the sub-sectors presented below.

- 1121 Cattle Ranching and Farming
- 112111 Beef Cattle Ranching and Farming
- 112112 Cattle Feedlots
- 11212 Dairy Cattle and Milk Production
- 11233 Turkey Production
- 11234 Poultry Hatcheries
- 1122 Hog and Pig Farming
- 1123 Poultry and Egg Production
- 11231 Chicken Egg Production
- 11239 Other Poultry Production
- 1124 Sheep and Goat Farming
- 11242 Goat Farming
- 11232 Broilers and Other Meat Type Chicken Production

#### Industry Sector Profile

Exhibit 2-3 indicates that the agriculture-livestock industry sector consists of over 1.0 million establishments that use a total of 135 million MWh of electricity per year. The cost of electricity for this sector averages 7 ¢/kWh. In addition, the sector as a whole releases a total of 193,703 million lbs./yr. of energy-related emissions ($CO_2$, $SO_2$ and $NO_x$). Thermal consumption is 119 million MWh while the total biogas production generation for this industry is 29.5 million metric tons/yr. All values represent year 2001 data. As noted previously, the detailed breakout profiling the agricultural-livestock sector can be found in Chapter 4.0.

**EXHIBIT 2-3: AGRICULTURE-LIVESTOCK INDUSTRY SECTOR PROFILE**

| | NUMBER OF ESTABLISHMENTS | ELECTRICITY COST (¢/kWh) | TOTAL EMISSIONS (MILLION lbs./yr) | TOTAL ELECTRICITY CONSUMPTION (MWh) | TOTAL THERMAL CONSUMPTION (MWh) | TOTAL BIOGAS PRODUCED (METRIC TON) |
|---|---|---|---|---|---|---|
| Total | 1,046,863 | 7.0 ¢ | 193,703 | 135,326,221 | 119,087,075 | 29,596,093 |

### Overview of Current Energy (Electrical and Thermal) Demand

Agriculture-livestock operations primarily have an electrical need (along with a minimal thermal need) to meet space heating and limited hot water requirements (for heating barns, henhouses, staff areas, etc.). The electrical energy need is typically met by the purchase of grid power. Agriculture-livestock operations do not have a need for premium power. It is likely that larger facilities have a small backup generator for emergency needs. The biogas emitted from agriculture-livestock waste has a high heat content and thus is a candidate fuel source.

As noted above, Exhibit 2-3 summarizes the total electricity consumption and total thermal energy consumption for the agriculture-livestock industry.

### 2.1.3 Banking Facilities

The Banking Facilities industry sector is best represented by two NAICS Codes. They are: NAICS 521 Monetary Authorities-Central Bank and NAICS Code 522320 Financial Transactions Processing, Reserve, and Clearinghouse Activities.

The Monetary Authorities-Central Bank sub-sector (NAICS Code 521) is comprised of establishments that perform central banking functions such as issuing currency, managing the Nation's money supply and international reserves, holding deposits that represent the reserves of other banks and other central banks, and acting as fiscal agent for the central government.

The Financial Transactions Processing, Reserve and Clearinghouse sub-sector (NAICS Code 522320) comprises establishments primarily engaged in providing one or more of the following: (1) financial transaction processing (except central banks); (2) reserve and liquidity services (except central banks); and (3) check or other financial instrument clearinghouse services (except central banks). Examples include:

- Automated clearinghouses, bank or check (except central bank)
- Bank clearinghouse associations
- Check clearing services (except central banks)
- Check clearinghouse services (except central banks)
- Check validation services
- Clearinghouses, bank or check
- Credit card processing services
- Electronic financial payment services
- Electronic funds transfer services
- Financial transactions processing (except central bank)
- Reserve and liquidity services (except central bank)

### Industry Sector Profile

Exhibit 2-4 illustrates that the banking facilities industry sector represented by NAICS codes 521 and 522320 comprise a total of 1,340 establishments as a potential market for fuel cell technologies. The total electricity consumption for this sector is approximately 679,667 MWh which result in energy-related emissions of 973 million lbs./year of $CO_2$, $SO_2$ and $NO_x$. The average price paid by banking facilities for electricity is 7.1 ¢/kWh. The thermal consumption for this industry sector is 339,000 MWh.

**EXHIBIT 2-4: BANKING FACILITIES INDUSTRY SECTOR PROFILE**

| | NUMBER OF ESTABLISHMENTS | ELECTRICITY COST (¢/kWh) | TOTAL EMISSIONS (MILLION lbs./yr) | TOTAL ELECTRICITY CONSUMPTION (MWh) | TOTAL THERMAL CONSUMPTION (MWh) | TOTAL BIOGAS PRODUCED (METRIC TON) |
|---|---|---|---|---|---|---|
| Total | 1,340 | 7.1 ¢ | 973 | 679,667 | 339,833 | 0 |

### Overview of Current Energy (Electrical and Thermal) Demand

Banking facilities require primarily electrical power with many applications requiring premium power and instantaneous/reliable backup power systems in order to avoid information losses and/or processing delays. Thermal needs are limited to climate control and hot water in most banking facilities. As noted above, Exhibit 2-4 summarizes the total electricity consumption and total thermal energy consumption for the banking industry.

## 2.1.4 Computer/Data Facilities

Facilities in the Computer/Data Facilities industry, also identified as NAICS 5142 Data Processing Services, may provide complete processing and preparation of reports from data supplied by customers; may perform specialized services, such as automated data entry services; or may make data processing resources available to clients on an hourly or timesharing basis.

### Industry Sector Profile

This industry comprises 8,914 establishments primarily engaged in providing electronic data processing services. The computer/data facilities industry sector as represented by NAICS 5142 uses a total of 2.4 million MWh/yr. of electricity resulting in a release of 3,465 million lbs./yr. of energy generation-related emissions ($CO_2$, $SO_2$ and $NO_x$). Approximately 1.2 million MWh/yr. of thermal energy is used and no biogas is generated. All figures represent year 2001 data.

**EXHIBIT 2-5: COMPUTER/DATA FACILITIES INDUSTRY SECTOR PROFILE**

| | NUMBER OF ESTABLISHMENTS | ELECTRICITY COST (¢/kWh) | TOTAL EMISSIONS (MILLION lbs./yr) | TOTAL ELECTRICITY CONSUMPTION (MWh) | TOTAL THERMAL CONSUMPTION (MWh) | TOTAL BIOGAS PRODUCED (METRIC TON) |
|---|---|---|---|---|---|---|
| Total | 8,914 | 7.1 ¢ | 3,465 | 2,420,892 | 1,210,446 | 0 |

### Overview of Current Energy (Electrical and Thermal) Demand

Both banking facilities and data processing facilities primarily require electrical power with most applications requiring premium power and instantaneous/reliable backup power systems in order to avoid information losses and/or processing delays. The economic stake also necessitates strong and reliable backup systems with fast start-up time. Thermal needs are limited to climate control and hot water in most data processing facilities. As noted above, Exhibit 2-5 summarizes the total electricity consumption and total thermal energy consumption for the computer/data facilities industry.

### 2.1.5 Computer-controlled Robotic-manufacturing Plants

Computer controlled Robotic-manufacturing plants were originally considered for inclusion as part of this study. However, the initial research for this sector revealed that computer-controlled or robotic manufacturing is more descriptive of an activity that occurs within various manufacturing processes as opposed to representing a single discreet industry. For example, computer controlled robotic manufacturing is commonly found in the automotive industry as well as other industrial sectors. As a result, this sector was eliminated from further consideration due to a lack of data to profile the proposed industry sector.

### 2.1.6 Hospitals

The Hospitals industry sector provides medical, diagnostic, and treatment services that include physician, nursing, and other health services to inpatients and the specialized accommodation services required by inpatients. Hospitals may also provide outpatient services as a secondary activity. Establishments in the hospitals sector provide inpatient health services, many of which can only be provided using specialized facilities and equipment. The hospitals industry sector defined as NAICS 622 includes the following sub-sectors:

- 6221 General Medical and Surgical Hospitals
- 62211 General Medical and Surgical Hospitals
- 622110 General Medical and Surgical Hospitals
- 6222 Psychiatric and Substance Abuse Hospitals
- 62221 Psychiatric and Substance Abuse Hospitals
- 622210 Psychiatric and Substance Abuse Hospitals
- 6223 Specialty (except Psychiatric and Substance Abuse) Hospitals
- 62231 Specialty (except Psychiatric and Substance Abuse) Hospitals
- 622310 Specialty (except Psychiatric and Substance Abuse) Hospitals

Exhibit 2-6 indicates that there are a total of 6,960 establishments in the hospitals industry sector. Collectively, they used approximately 42 million MWh/yr. of electricity at an average cost of 6.3 ¢/kWh. In addition, these hospitals generated 60,195 million lbs./yr of energy-related emissions ($CO_2$, $SO_2$, and $NO_{x)}$ and used 68.5 million MWh/yr. of thermal power.

**EXHIBIT 2-6: HOSPITALS INDUSTRY SECTOR PROFILE**

| | NUMBER OF ESTABLISHMENTS | ELECTRICITY COST (¢/kWh) | TOTAL EMISSIONS (MILLION lbs./yr) | TOTAL ELECTRICITY CONSUMPTION (MWh) | TOTAL THERMAL CONSUMPTION (MWh) | TOTAL BIOGAS PRODUCED (METRIC TON) |
|---|---|---|---|---|---|---|
| Total | 6,960 | 6.3 ¢ | 60,195 | 42,054,057 | 68,548,113 | 0 |

**Overview of Current Energy (Electrical and Thermal) Demand**

Hospitals require both electrical and thermal power ("high heat"). They purchase substantive grid power, often have boilers onsite for thermal power, and may also utilize co-generation. Pursuant to the around-the-clock critical, sophisticated activities ongoing at a hospital, both premium power and instantaneous/reliable backup power systems (likely via diesel fuel) are mandatory. As noted above, Exhibit 2-6 summarizes the total electricity consumption and total thermal energy consumption for the hospitals industry sector.

### 2.1.7 Industrial Parks

Industrial parks are place-based areas where businesses can be located together. The industrial park is typically owned by a single entity or individual and the land is leased or rented by businesses. Industrial parks were initially considered as part of the study because businesses could potentially organize together to meet their co-generation needs. However, it was difficult to identify industrial parks using the NAICS. As a result, this industry sector was eliminated from further study.

### 2.1.8 Landfills

The landfills industry sector is characterized by NAICS Code 562212 Solid Waste Landfill. The landfills industry sector is comprised of 1,515 establishments primarily engaged in: (1) operating landfills for the disposal of non-hazardous solid waste, or (2) the combined activity of collecting and/or hauling non-hazardous waste materials within a local area and operating landfills for the disposal of non-hazardous solid waste. Examples include, but are not limited to:

- Dumps, non-hazardous solid waste (e.g., trash)
- Garbage disposal landfills
- Garbage dumps
- Landfills
- Refuse collecting and operating solid waste landfills
- Refuse disposal landfills
- Rubbish disposal landfills
- Sanitary landfills
- Sludge disposal sites
- Solid waste landfills combined with collection and/or local hauling of non-hazardous waste material
- Solid waste landfills, non-hazardous
- Trash disposal landfills
- Waste disposal landfills, non-hazardous solid

## Industry Sector Profile

Of the 1,515 landfill establishments, 39% (595 establishments) employ 1 to 4 employees. Collectively, the facilities in this NAICS Code use 370,301 MWh of electricity at a cost of 7.8 ¢/kWh. Fifty-two percent of the energy required in this industry is used by only 2.6% (40) of the facilities (i.e., the largest facilities). In 1999, landfills generated 530 million lbs./yr. of energy-related emissions ($CO_2$, $SO_2$ and $NO_x$). This industry collectively generated 16.5 million metric tons/yr. of biogas.

**EXHIBIT 2-7: LANDFILLS INDUSTRY SECTOR PROFILE**

| | NUMBER OF ESTABLISHMENTS | ELECTRICITY COST (¢/kWh) | TOTAL EMISSIONS (MILLION lbs./yr) | TOTAL ELECTRICITY CONSUMPTION (MWh) | TOTAL THERMAL CONSUMPTION (MWh) | TOTAL METHANE PRODUCED (METRIC TON) |
|---|---|---|---|---|---|---|
| TOTAL | 1,515 | 7.8 ¢ | 530 | 370,301 | 0 | 16,540,850 |

## Overview of Current Energy (Electrical and Thermal) Demand

Landfills do not have a substantive electrical need and have little to no thermal need other than possible minimal space heating (i.e., climate control) of buildings. This simple generation energy need is typically met by the purchase of grid power; although, some sites also utilize onsite generation utilizing biogas (primarily methane) collected from the landfill itself to produce electricity for use or sale. Landfills do not have a need for premium power. However, a small backup generator is common in case of emergency. The biogas collected from the landfill may also be a suitable fuel source for fuel cells. As noted above, Exhibit 2-7 summarizes the total electricity consumption and total thermal energy consumption for the Landfill industry.

### 2.1.9 Logging

The wood processing industry sector with potential power generation applications for fuel cells is best represented by two NAICS Codes 113310 Logging and 322 Paper Manufacturing. The logging facility is described below. The logging industry comprises establishments primarily engaged in one or more of the following: (1) cutting timber; (2) cutting and transporting timber; and (3) producing wood chips in the field.

#### Industry Sector Profile

Exhibit 2-8 indicates that a total of 13,011 establishments are included in NAICS Code 113310. These establishments collectively use 327,301 MWh/yr. of electricity at an average cost of 5.5 ¢/kWh resulting in a total energy-related emissions of 468 million lbs./yr. ($CO_2$, $SO_2$ and $NO_x$).

**EXHIBIT 2-8: LOGGING INDUSTRY SECTOR PROFILE**

| | NUMBER OF ESTABLISHMENTS | ELECTRICITY COST (¢/kWh) | TOTAL EMISSIONS (MILLION lbs./yr) | TOTAL ELECTRICITY CONSUMPTION (MWh) | TOTAL THERMAL CONSUMPTION (MWh) | TOTAL BIOGAS PRODUCED (METRIC TON) |
|---|---|---|---|---|---|---|
| Total | 13,011 | 5.5 ¢ | 468 | 327,301 | 0 | 0 |

#### Overview of Current Energy (Electrical and Thermal) Demand

Logging operations are usually geographically located off of the power grid and thus utilize remote power (i.e., primarily diesel) to meet their electrical needs. Logging operations do not usually have a thermal energy need except for heating of staff quarters and hot water. Logging operations do not have a need for premium power. As noted above, Exhibit 2-8 summarizes the total electricity consumption and total thermal energy consumption for the Logging Industry sector.

### 2.1.10 Military Bases

Military Bases, identified as NAICS Code 928110, comprises government establishments of the Armed Forces, including the National Guard, primarily engaged in national security and related activities. This industry specifically includes the following types of facilities:

- Air Force
- Air traffic control, military
- Armed forces
- Army
- Courts, military
- Marine Corps

C Military bases and camps
C Military police
C Military reserve armories and bases
C Military training schools (except academies)
• Navy

### Industry Sector Profile

As indicated in Exhibit 2-9, a total of 466 establishments comprise NAICS Code 928110 National Security. This subsector utilizes 13.3 million MWh/yr. of electricity at a cost of 7.3 ¢/kWh and generates 19,155 million lbs./yr of energy-related emissions ($CO_2$, $SO_2$ and $NO_x$). This sector also used 11.7 million MWh/yr. of thermal energy.

**EXHIBIT 2-9: MILITARY BASE INDUSTRY SECTOR PROFILE**

| PERSONNEL | NUMBER OF ESTABLISHMENTS | ELECTRICITY COST (¢/kWh) | TOTAL EMISSIONS (MILLION lbs./yr) | TOTAL ELECTRICITY CONSUMPTION (MWh) | TOTAL THERMAL CONSUMPTION (MWh) | TOTAL BIOGAS PRODUCED (METRIC TON) |
|---|---|---|---|---|---|---|
| 1,518,224 | 466 | 7.3 ¢ | 19,155 | 13,382,537 | 11,776,633 | 0 |

### Overview of Current Energy (Electrical and Thermal) Demand and Sources

Depending on the scale and type of activities performed on a particular military base, power requirements will vary significantly. In general, most military bases require both electrical and thermal energy. Some larger bases generate their own power from plants fueled by natural gas, coal or diesel. Most other bases purchase grid power. While some common military base activities like equipment and vehicle maintenance do not necessitate premium power or tightly coupled cogeneration, other military base operations (e.g., hospital and/or mission critical needs) can require premium and backup power. Military bases also frequently utilize traditional cogeneration to meet climate control, hot water, and process steam needs. As noted above, Exhibit 2-10 summarizes the total electricity consumption and total thermal energy consumption for military bases.

### 2.1.11 Paper Manufacturing

The wood processing industry sector with potential fuel cell power generation applications is best represented by two NAICS Codes 113310 Logging and 322 Paper Manufacturing. The paper manufacturing sector is described below. This industry group comprises establishments primarily engaged in manufacturing pulp, paper, or paperboard. Any establishment that makes paper (including paperboard), either alone or in combination with pulp manufacturing or paper converting, is classified as a paper or paperboard mill. Establishments that make pulp without making paper are classified as pulp mills. This industry includes the following sub-sectors:

- 32211 Pulp Mills
- 322110 Pulp Mills
- 32212 Paper Mills
- 322121 Paper (except Newsprint) Mills
- 322122 Newsprint Mills
- 32213 Paperboard Mills
- 322130 Paperboard Mills

### Industry Sector Profile

There are a total of 549 paper manufacturing establishments included in NAICS Code 3221. These establishments use 102.4 million MWh/yr. of electricity at a cost of 4.1 ¢/kWh. The sector also uses 291.4 million MWh/yr. of thermal energy. The total energy-related emissions ($CO_2$, $SO_2$ and $NO_x$) released is 146,639 million lbs./yr.

**EXHIBIT 2-10: PAPER MANUFACTURING INDUSTRY SECTOR PROFILE**

| | NUMBER OF ESTABLISHMENTS | ELECTRICITY COST (¢/kWh) | TOTAL EMISSIONS (MILLION lbs./yr) | TOTAL ELECTRICITY CONSUMPTION (MWh) | TOTAL THERMAL CONSUMPTION (MWh) | TOTAL BIOGAS PRODUCED (METRIC TON) |
|---|---|---|---|---|---|---|
| Total | 549 | 4.1 ¢ | 146,639 | 102,445,855 | 291,472,517 | 0 |

### Overview of Current Energy (Electrical and Thermal) Demand

Paper manufacturing requires both substantive electrical and thermal energy ("high heat"). These needs can be met either by onsite tightly coupled co-generation fueled with by-product wood sources (at integrated plants) or by purchased grid power (primarily by non-integrated paper mills). Historically, paper manufacturing did not have a need for premium power; however, as the processes become more computer and robotic dependent, the need for premium power is expected to grow. Paper manufacturing operations that generate their own power also may sell electricity back to the grid. As noted above, Exhibit 2-10 summarizes the total electricity consumption and total thermal energy consumption for the Paper Manufacturing industry.

### 2.1.12 Telecommunications Support

Identified as NAICS Code 5133 Telecommunications, this industry group comprises establishments primarily engaged in operating, maintaining or providing access to facilities for the transmission of voice, data, text, and full motion picture video between network termination points and telecommunications reselling. Transmission facilities may be based on a single technology or a combination of technologies. This industry includes the following sub-sectors:

- 51331 Wired Telecommunications Carriers
- 513310 Wired Telecommunications Carriers

- 51332 Wireless Telecommunications Carriers (except Satellite)
- 513321 Paging
- 513322 Cellular and Other Wireless Telecommunications
- 51333 Telecommunications Resellers
- 513330 Telecommunications Resellers
- 51334 Satellite Telecommunications
- 513340 Satellite Telecommunications

### Industry Sector Profile

A total of 36,942 establishments are included in NAICS Code 5133. These establishments collectively use 11.8 million MWh/yr. of electricity at an average cost of 7.1 ¢/kWh. Establishments that employ between 100 and 1000+ employees represent 5.8% of the total number of establishments in the sector and use 73% of the electricity. Energy-related emissions ($CO_2$, $SO_2$ and $NO_x$) totaled 16,895 million lbs./yr. for the entire sector. Approximately 6 million MWh/yr. of thermal energy was used by this sector.

**EXHIBIT 2-11: TELECOMMUNICATIONS SUPPORT INDUSTRY SECTOR PROFILE**

| | NUMBER OF ESTABLISHMENTS | ELECTRICITY COST (¢/kWh) | TOTAL EMISSIONS (MILLION lbs./yr) | TOTAL ELECTRICITY CONSUMPTION (MWh) | TOTAL THERMAL CONSUMPTION (MWh) | TOTAL BIOGAS PRODUCED (METRIC TON) |
|---|---|---|---|---|---|---|
| Total | 36,942 | 7.1 ¢ | 16,895 | 11,803,093 | 5,901,546 | 0 |

### Overview of Current Energy (Electrical and Thermal) Demand

Similar to banking facilities, telecommunications support facilities primarily require electrical power, with most applications requiring premium power and instantaneous/reliable backup power systems in order to avoid information losses and/or processing delays. The economic stake is such that they also necessitate strong and reliable backup systems with fast start-up time. Thermal needs are limited to climate control and hot water in most telecommunications support facilities. As noted above, Exhibit 2-12 summarizes the total electricity consumption and total thermal energy consumption for the telecommunications support industry.

### 2.1.13 Wastewater Treatment Plants

The wastewater treatment plant (WWTP) industry is identified as NAICS Code 22132 Sewage Treatment Facilities. This industry comprises establishments primarily engaged in operating sewer systems or sewage treatment facilities that collect, treat, and dispose of waste. Examples include, but are not limited to:

- Collection, treatment, and disposal of waste through a sewer system

C Sewage disposal plants

C Sewage treatment plants or facilities

- Sewer systems
- Waste collection, treatment, and disposal through a sewer system

### Industry Sector Profile

The WWTP industry includes those facilities, typically owned and operated by some form of local government that treat wastewater collected from a combination of residential, commercial, and industrial sources. According to the 1996 Clean Water Needs Survey, there are a total of 3,452 WWTPs that use anaerobic digestion to treat sewage. Of those plants, 266 plants currently utilize the digester gas produced from the anaerobic digestion. This industry sector collectively uses 6.6 million MWh/yr. of electricity and 20.1 million MWh/yr. of thermal energy. The cost of the electricity is 7 ¢/kWh. In addition to releasing 9,507 million lbs./yr. of energy-related emissions ($CO_2$, $SO_2$ and $NO_x$), WWTPs produced 157,143 metric tons of biogas/yr.

**EXHIBIT 2-12: WASTEWATER TREATMENT PLANT INDUSTRY SECTOR PROFILE**

| | NUMBER OF ESTABLISHMENTS | ELECTRICITY COST (¢/kWh) | TOTAL EMISSIONS (MILLION lbs./yr) | TOTAL ELECTRICITY CONSUMPTION (MWh) | TOTAL THERMAL CONSUMPTION (MWh) | TOTAL BIOGAS PRODUCED (METRIC TON) |
|---|---|---|---|---|---|---|
| Total | 3,452 | 7.0 ¢ | 9,507 | 6,641,999 | 20,180,693 | 157,143 |

### Overview of Current Energy (Electrical and Thermal) Demand and Sources

WWTPs primarily require substantive electricity for their operation, with only a small amount of thermal energy, possibly generated from onsite boilers or traditional co-generation needed for the heating of process water ("low heat"). This simple generation electrical need is typically met by purchased grid power, along with a smaller capacity onsite backup generator (most likely diesel fueled) for operating essential equipment (e.g., pumps) in emergency situations. WWTPs do not have a need for premium power.

A number of WWTPs produce anaerobic digester gas (ADG) as a by-product of their processing. Since the ADG has a high heat content, some of these WWTPs recover the ADG as a fuel source for either process thermal heat or powering a generator to supplement purchased grid power. Typically, WWTPs do not sell electricity back to the grid. As an alternative, ADG could be a fuel source for fuel cells. As noted above, Exhibit 2-12 summarizes the total electricity consumption and total thermal energy consumption for the WWTP industry.

## 2.2 Additional Industry Sectors

The research conducted for the industrial sectors presented earlier, identified two additional industry sectors that appeared to be promising candidates for fuel cell technologies. These sectors included Travel Accommodations and Educational Services. A discussion of each follows.

### 2.2.1 Traveler Accommodations

Industries in the Traveler Accommodations sector provide lodging or short-term accommodations for travelers, vacationers, and others. There is a wide range of establishments in these industries. Some provide lodging only while others provide meals, laundry and recreational facilities as well as lodging. Lodging establishments are classified in this sector even if the provision of complementary services generates more revenue. The type of complementary services provided vary by establishment.

The Traveler Accommodations industry group includes establishments that primarily provide traditional types of lodging services. This group includes hotels and motels (NAICS 72111), casino hotels (NAICS 72112) and bed and breakfast inns (NAICS 72119). In addition to lodging, these establishments may provide a range of other services to their guests. Establishments that manage short-stay accommodation establishments (e.g., hotels and motels) on a contractual basis are classified in this sub-sector if they both manage the operation and provide the operating staff. Such establishments are classified based on the type of facility managed and operated.

The Traveler Accomodations sector is identified as NAICS Code 7211. It is divided into the following subsectors:

- 72111 Hotels (except Casino Hotels and Motels
- 72112 Casino Hotels
- 72119 Other Traveler Accomodation
- 721191 Bed-and-Breakfast Inns

#### Industry Sector Profile

The Traveler Accommodations sector is comprised of 48,962 establishments that collectively used 26.3 million MWh/yr. of electricity. The cost for this electricity averages 7.0 ¢/kWh. The thermal consumption for the sector totaled 38.5 million MWh/yr. while energy-related emissions ($CO_2$, $SO_2$ and $NO_x$) totaled 37,762 million lbs./yr.

**EXHIBIT 2-13 : TRAVELER ACCOMMODATIONS INDUSTRY SECTOR PROFILE**

| | NUMBER OF ESTABLISHMENTS | ELECTRICITY COST (¢/kWh) | TOTAL EMISSIONS (MILLION lbs./yr) | TOTAL ELECTRICITY CONSUMPTION (MWh) | TOTAL THERMAL CONSUMPTION (MWh) | TOTAL BIOGAS PRODUCED (METRIC TON) |
|---|---|---|---|---|---|---|
| Total | 48,962 | 7.0 ¢ | 37,762 | 26,381,571 | 38,517,093 | 0 |

### Overview of Current Energy (Electrical and Thermal) Demand

Traveler accomodations have a need for electrical and thermal power for heat. Hotels usually purchase their electricity from the grid and generate steam from onsite boilers. Most hotels also have a backup system (fueled by diesel) in case of emergency to maintain guest/customer satisfaction. Hotels traditionally do not generate wastes (e.g. biogas) that can be used to generate power. As noted above, Exhibit 2-13 summarizes the total electricity consumption and total thermal energy consumption for hotels.

### 2.2.2 Educational Services

The Educational Services sector is comprised of establishments that provide instruction and training in a wide variety of subjects. The instruction and training is provided by specialized establishments, such as schools, colleges, universities, and training centers. These establishments may be privately owned and operated for profit or not for profit, or they may be publicly owned and operated. They may also offer food and accommodation services to their students.

Educational Services are usually delivered by teachers or instructors that explain, tell, demonstrate, supervise, and direct learning. It can be adapted to the particular needs of the students. For example, sign language can replace verbal language for teaching students with hearing impairments. All industries in this sector share this common process: labor inputs of instructors with the requisite subject matter expertise and teaching ability.

Educational Services is included in NAICS code 611. The subsectors included in this sector are presented below.

- 611 Educational Services
- 6111 Elementary and Secondary Schools
- 61111 Elementary and Secondary Schools 6112 Junior Colleges
- 61121 Junior Colleges
- 6113 Colleges, Universities, and Professional Schools
- 61131 Colleges, Universities, and Professional Schools
- 6114 Business Schools and Computer and Management Training
- 61141 Business and Secretarial Schools
- 61142 Computer Training
- 61143 Professional and Management Development Training
- 6115 Technical and Trade Schools
- 61151 Technical and Trade Schools
- 611511 Cosmetology and Barber Schools
- 611512 Flight Training
- 611513 Apprenticeship Training
- 611519 Other Technical and Trade Schools
- 6116 Other Schools and Instruction
- 61161 Fine Arts Schools
- 61162 Sports and Recreation Instruction
- 61163 Language Schools

### Industry Sector Profile

This sector is comprised of 66,492 establishments. This sector used approximately 24.6 million MWh/yr. of electricity at an average price of 8.0 ¢/kWh. The thermal energy used was 43.8 million MWh/yr. and 35,281 million lbs./yr. of energy-related emissions ($CO_2$, $SO_2$ and $NO_x$) were released.

**EXHIBIT 2-14 : EDUCATIONAL SERVICES INDUSTRY SECTOR PROFILE**

| | Number of Establishments | Electricity Cost (¢/kWh) | Total Emissions (million lbs./yr) | Total Electricity Consumption (MWh) | Total Thermal Consumption (MWh) | Total Biogas Produced (metric ton) |
|---|---|---|---|---|---|---|
| Total | 66,492 | 8.0 ¢ | 35,281 | 24,648,321 | 43,874,011 | 0 |

### Overview of Current Energy (Electrical and Thermal) Demand

The characteristics of the power demands at establishments within the educational services (e.g., schools) industry depend upon the scale and type of activities performed at a school and may vary significantly. Activities like classroom teaching do not necessitate premium power or tightly coupled cogeneration, but other activities, such as computer labs and/or health clinics may. Schools usually have some level of backup systems for critical operations at a minimum. Larger school operations, such as university campuses, may generate their own power (electrical and thermal) while smaller operations purchase electricity and generate thermal power from boilers onsite. Generally, no wastes or biofuels are generated from schools that could be used as an energy source.

As noted above, Exhibit 2-14 summarizes the total electricity consumption and total thermal energy consumption for schools.

## 2.3 Summary

Although a total of 14 industry sectors were initially profiled, only 12 were deemed feasible for further consideration as candidates for fuel cell technologies. These 12 industry sectors are included in the adjacent text box. The research conducted to identify and evaluate promising fuel cell technologies is presented in Chapter 3.0.

**Candidate Industrial Sectors**

< Agriculture-Livestock
< Banking Facilities
< Computer/Data Facilities
< Educational Services
< Landfills
< Logging
< Hospitals
< Military Bases
< Paper Manufacturing
< Telecommunications Support
< Traveler Accommodations
< Wastewater Treatment Plants

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# 3.0 Fuel Cell Technologies

The applicability of a given fuel cell technology to a specific industry is based on how well that technology meets the technical, economic, environmental, and institutional demands for the industry. This chapter characterizes the existing fuel cell technologies in terms of the benefits they offer to specific industries. The benefit factors provide a baseline or standard against which to compare the fuel cell technologies to one another and to evaluate the application of the fuel cell technologies within a particular industry. Section 3.1 of this chapter presents the benefit factors that will be used to assess the fuel cell technologies. Section 3.2 describes the current state of four promising fuel cell technologies vis-a-vis the associated benefit factors. A comparison of the fuel cell technologies is presented in Section 3.3. As a next step, the characteristics (i.e., benefit factors) for each fuel cell technology were compared to the industry specific demands to help determine which industry sector represents the greatest potential for marketing/implementing fuel cell technology.

## 3.1 Benefit Factors for Evaluating Fuel Cell Technologies

Literature searches, bibliography reviews, Internet searches and phone interviews were used to gather information regarding the available fuel cell technologies for this study. Research developed by a variety of organizations including DOE, the Department of Defense, EPA, Electric Power Research Institute, and fuel cell vendors was compiled to assess the fuel cell technologies. Information on factors related to fuel cell technology performance, costs, product status and development time frame was collected. These factors provide a standard or baseline against which to measure and compare the various fuel cell technologies. From this information, a detailed list of benefit factors for the fuel cell technologies were developed (Exhibit 3-1). Benefit factors provide a method or measure of determining whether it may be feasible or beneficial to use a specific fuel cell technology.

To help quantify this applicability, technical, economic, environmental, and institutional benefit factors were identified. Benefit factors in the areas of technical performance costs and savings, environmental performance, and institutional barriers were identified. These and other benefit factors were developed as a tool to assess/evaluate the potential opportunity for using a particular fuel cell technology in the industrial sectors identified earlier.

*Technical factors* relate to the performance characteristics of the technology as well as to their present stage of commercialization.

*Economic factors* include the costs of installation, operation, and maintenance, as well as the revenues or avoided expenditures from using captured biogas.

*Environmental factors* include all the potential releases into the environment associated with using the technology, as well as potential emissions credits and life-cycle related benefits.

*Institutional factors* refer to the subjective elements that motivate establishments or organizations (local governments in the case of wastewater treatment plants) to accept fuel cell technology or that act as barriers to that acceptance.

A detailed list of the benefit factors in each of these categories is shown in Exhibit 3-1.

The benefit factors presented in the tables that follow provide data that are both quantitative and qualitative. Some data relate to the fuel cell technology and other data, while more subjective, evaluate the factors that may motivate or discourage/prevent/prohibit an industry from adopting fuel cell technology.

**EXHIBIT 3-1: BENEFIT FACTORS FOR EVALUATION OF FUEL CELL TECHNOLOGY**

| FACTOR | EVALUATION DESCRIPTION |
|---|---|
| **TECHNICAL** | |
| **Engineering History Assessment** | |
| Technology maturity | R&D phase/commercially available |
| **Physical Plant Process Impacts** | |
| Physical space requirements | Footprint size and volume occupied |
| Infrastructure requirements | Itemized list of requirements |
| Ease of operation | Number of operation hours |
| Responsiveness | Time from cold start to full load (hours) |
| **Production Characteristics** | |
| Co-generation options | Yes/no; description of co-generation output |
| Quality of power produced | Qualitative description |
| Output reliability/consistency | High, medium, low (based on professional judgement) |
| Fuel flexibility | Quality of fuel requirement (min/max Btu) |
| **ECONOMIC** | |
| **Costs** | |
| Acquisition costs (purchase and installation) | Dollars $/kW |
| Annual operation and maintenance costs | Dollars $/yr |
| Lead Time | Time (from procurement order) to working steady state |
| Other annual indirect impacts (e.g., liability, environmental) | Qualitative description |
| Service life | Years of useful life |
| End-of-Life value/cost | Salvage value or cost |
| **Revenues** | |
| Annual revenue from sale of output | Dollars/yr |
| Annual business energy tax credits/rebates (Federal, State, local) | Dollars (in current year values) |

**EXHIBIT 3-1: BENEFIT FACTORS FOR EVALUATION OF FUEL CELL TECHNOLOGY**

| FACTOR | EVALUATION DESCRIPTION |
|---|---|
| Emissions credits | List |
| **ENVIRONMENTAL** | |
| **Pollution Reduction** | |
| Air emissions | Pounds by constituent ($CO_2$, $NO_x$, $SO_x$, greenhouse gases) |
| Wastewater releases | Gallons/pounds by constituent |
| Solid waste (non-hazardous and hazardous) | Pounds of solid waste/ pounds of hazardous wastes |
| **Stewardship** | |
| Resource usage (water, fuel feedstock) | Pounds or other applicable unit |
| Life-Cycle related benefits | Qualitative discussion of known issues |
| **INSTITUTIONAL** | |
| **Current Regulations** | |
| Regulatory barriers | Qualitative description and judgement (high, medium, low) |
| **Plant Management** | |
| Management/customer acceptance | Qualitative description and judgement (high, medium, low) |
| **Plant Operators and Personnel** | |
| Staff expertise/training required | Qualitative description and judgement (high, medium, low) |

## 3.2 Evaluation Process

Information and data were compiled for these benefit factors for each of the fuel cell technologies. These benefit factors were analyzed to determine the most promising fuel cell technology that meets the needs of a particular industry market. A description of each type of fuel cell is given in this section, along with a summary of their performance specifications.

### 3.2.1 Phosphoric Acid Fuel Cell (PAFC)

The PAFC, using phosphoric acid as an electrolyte, is the most popular type of fuel cell and has already found its way into many commercial applications. The PAFC produces alternating current (AC) power in a non-combustion process from natural gas. The fuel processor oxidizes the methane, $CH_4$, in natural gas into usable hydrogen. The power section yields direct current via movement of hydrogen ions through the phosphoric acid electrolyte, $H_3PO_4$. Exhibit 3-2 below summarizes the main performance characteristics of the PAFC.

**EXHIBIT 3-2: CHARACTERISTICS OF PHOSPHORIC ACID FUEL CELL (UNIT SIZE OF 200–250 KW IN 2001 AND 50-250 KW IN 2010)**

| BENEFIT FACTOR | CHARACTERISTICS |
|---|---|
| **TECHNICAL** | |

**EXHIBIT 3-2: CHARACTERISTICS OF PHOSPHORIC ACID FUEL CELL (UNIT SIZE OF 200–250 KW IN 2001 AND 50-250 KW IN 2010)**

| BENEFIT FACTOR | CHARACTERISTICS |
|---|---|
| Technology Maturity | Commercially available |
| Physical space requirements | 160–175 KW/ft$^3$ power density [2]<br>2,000 ft$^3$ (10'X10'X18' + 4'X14'X4')<br>41,700 lbs. |
| Infrastructure requirements | Gas hydrocarbon fuel, electric<br>480/277 V, 60 Hz, 3 phase<br>400/230 V, 50 Hz, 3 phase |
| Ease of operation | Remote access and control |
| Responsiveness/Start-up time | Comparable to traditional power grid |
| Co-generation options | Excellent<br>Standard thermal output @ 140 EF<br>High heat option @ 250 EF<br>80% [5] combined heat and power<br>Operating temperature (EC): 190–220 [2,3] |
| Fuel efficiency/Quality of power produced | High efficiency<br>Electrical Efficiency (LHV, %): 35–40 (35–45) [1,4,5,6]<br>Overall System Efficiency (%): 35–55 [1] |
| Output reliability/consistency | Reliability between 99.9% and 99.9999% |
| Fuel flexibility | Natural gas, Methane, Propane, Biogas<br>Natural gas, 1,900 ft$^3$/hr or 86 lbs./hr of consumption [3]<br>Biogas, 3,200 ft$^3$/hr or 229 lbs./hr of consumption (assuming composition of biogas is primarily methane)<br>Also able to run on dual fuel |

## EXHIBIT 3-2: CHARACTERISTICS OF PHOSPHORIC ACID FUEL CELL (UNIT SIZE OF 200–250 KW IN 2001 AND 50-250 KW IN 2010)

| BENEFIT FACTOR | CHARACTERISTICS |
|---|---|
| **ECONOMIC** | |
| Acquisition costs ($/kW) | 2,000–4,500 (750–1,000 in 2010) [1,3] |
| Annual operation and maintenance (¢/KWh) | 1.5–2 (0.5–1.5 in 2010) [1]<br>Quarterly / annual: routine preventative maintenance/inspection<br>5–10 years: stack replacement<br>Remote monitoring/autonomous operation possible[1] |
| Lead time | 16 weeks from date of contract agreement |
| Other annual indirect costs (e.g., liability, environmental) | Fuel cell maintenance cost ($/yr): 35,000[2] |
| Service life (years) | 20–30 [1,6] |
| End-of-life value or cost | Unknown<br>95% recyclable by weight<br>5% to landfill (thermal insulation, carbon from cell stack)<br>0.03% hazardous waste (phosphoric acid, condenser rinse water with chromium) |
| Annual revenue from sale of output | Site specific |
| Annual business energy tax credits/rebates (Federal, State, Local) | May be eligible for grants/tax credits. Programs will vary by State.<br>(Grant of 1,000 $/KW [2] towards purchase possibly available) |
| Emissions Credit | None identified |
| **ENVIRONMENTAL** | |
| Air emissions (g/KWh) | $CO_2$: 360–570 @ 35–55% efficiency, 270–310 @ 65-75% efficiency [1,4]<br>$SO_x$: Negligible (approx. 0.02[3])<br>$NO_x$: Negligible (approx. 0.02[1,3]) |
| Wastewater releases | 300 lbs./yr (managed as hazardous wastes) |
| Solid waste (non-hazardous and hazardous) | 150 lbs./yr (unknown make-up) |
| Resource usage (water, fuel, feedstock) | 1,900 $ft^3$ of natural gas per hour [3] 200 kW output |
| Life-Cycle related benefits | Energy $ saved per hour of run time: 6.74 [4]<br>Little hazardous waste generated<br>Mostly recyclable<br>Few hazardous materials (lead battery, chromium in water system, phosphoric acid) |
| **INSTITUTIONAL** | |
| Regulatory barriers | Needs interconnectivity standards and codes |
| Management/customer acceptance | High, over 225 units delivered worldwide |
| Staff expertise/training required | Skilled staff, need training to maintain |
| Disadvantages | Small module sizes (200–250kW)<br>Relatively complex fuel processing<br>Stack is sensitive to CO poisoning (requires <10 ppm CO)<br>Requires precious metal catalysts |

**EXHIBIT 3-2: CHARACTERISTICS OF PHOSPHORIC ACID FUEL CELL (UNIT SIZE OF 200–250 KW IN 2001 AND 50-250 KW IN 2010)**

| BENEFIT FACTOR | CHARACTERISTICS |
|---|---|

1 "Opportunities for Micropower and Fuel Cell/Gas Turbine Hybrid Systems in Industrial Applications," Vol. 1, Arthur D. Little, January 2000.
2 International Fuel Cell/ONSI (http://www.ifc.com)
3 "Fuel Cell Operation on ADG," U.S. EPA Fuel Cell Workshop, Cincinnati, OH, June 26–27, 2001.
4 "DoD Experiences Implementing Fuel Cell Technology," U.S. EPA Fuel Cell Workshop, Cincinnati OH, June 26–27, 2001.
5 "EPA Programs Supporting Fuel Cell Implementation," Energy Supply and Industry Branch, U.S. EPA.
6 http://www.dodfuelcell.com

### 3.2.2 Proton Exchange Membrane Fuel Cell (PEMFC)

The PEMFC uses as its electrolyte a polymer membrane. With a solid electrolyte, there is no electrolyte loss, and the stack life is much longer. The electrolyte is sandwiched between the anode and cathode, and the three components are sealed together under heat and pressure to produce a single "membrane/electrode assembly" (MEA). The anode and cathode are contacted on the back side by flow field plates made of graphite in which channels have been formed. The ridges between the channels make electrical contact with the backs of the electrodes and conduct the current to the external circuit. The channels supply fuel to the anode and oxidant to the cathode. Exhibit 3-3 below summarizes the main performance characteristics of PEMFC's.

**EXHIBIT 3-3: CHARACTERISTICS OF PROTON EXCHANGE MEMBRANE FUEL CELL (UNIT SIZE OF 200–250 KW IN 2001 AND 50-250 KW IN 2010)**

| BENEFIT FACTOR | CHARACTERISTICS |
|---|---|
| **TECHNICAL** | |
| Technology Maturity | Limited commercial availability. Ballard Generation Systems is currently field testing nine stationary units. They expect broader commercial availability in 2003 |
| Physical space requirements | 5.4–14.2 KW/ft$^3$ power density [2, 3, 10]<br>3,000 ft$^3$ 30'X10'X10' (l X w X h) for a 250 KW unit |
| Infrastructure requirements | Gas hydrocarbon fuel, electric<br>Air, ambient is okay<br>No water needed |
| Ease of operation | Solid electrolyte reduces corrosion and management problems |
| Responsiveness/Start-up time | Rapid |
| Co-generation options | Limited co-generation potential, but Ballard is field testing co-generation options on a 250 KW unit<br>Operating temperature ($^E$C): 50–100 [2, 3, 4, 5, 7, 8, 9] |
| Quality of power produced | Electrical Efficiency (LHV, %): 25–40 (30-40 in 2008, 35–45 in 2010) [4, 6, 8]<br>Overall System Efficiency (%): 35–55 [2, 3] |

**EXHIBIT 3-3: CHARACTERISTICS OF PROTON EXCHANGE MEMBRANE FUEL CELL (UNIT SIZE OF 200–250 KW IN 2001 AND 50-250 KW IN 2010)**

| BENEFIT FACTOR | CHARACTERISTICS |
|---|---|
| Output reliability/consistency | Constant power production<br>Power available 99.9999% of the time<br>High efficiency |
| Fuel flexibility | Natural gas, Methane, Propane, Biogas |
| **ECONOMIC** | |
| Acquisition costs ($/kW) | >$10,000 (900–1,500 in 2008, and 200–800 $/KW for a 1,000 KW unit in 2015) [8] |
| Annual operation and maintenance (¢/KWh) | 1.5–2.0 (0.5–1.5 in 2010) [4] |
| Lead time | Unknown |
| Other annual indirect costs (e.g., liability, environmental) | Unknown |
| Service life (years) | 20–30 [1, 4] |
| End-of-life value or cost | Unknown |
| Annual revenue from sale of output | Site specific |
| Annual business energy tax credits/rebates (Federal, State, Local) | May be eligible for grants/tax credits. Programs will vary by State.<br>(Grant of 1,000 $/KW [2] towards purchase possibly available) |
| Emissions Credit | None identified |
| **ENVIRONMENTAL** | |
| | |
| Air emissions (g/KWh) | $CO_2$: 360–570 @ 35–55% efficiency, 270–310 @ 65–75% efficiency [4, 8, 9]<br>$SO_2$: Negligible (approx. 0.04) [4, 8, 9]<br>$NO_x$: Negligible (approx. 0.04) [4, 8, 9] |
| Wastewater releases | Unknown |
| Solid waste (non-hazardous and hazardous) | None anticipated |
| Resource usage (water, fuel, feedstock) | Similar to PAFC |
| Life-Cycle related benefits | Mostly recyclable<br>Very little wear because no moving parts are involved in the power generating process |
| **INSTITUTIONAL** | |
| Regulatory barriers | Needs interconnectivity standards and codes |
| Management/customer acceptance | High acceptance in vehicles. Being marketed as “low noise, low maintenance, high reliability, no vibration” |
| Staff expertise/training required | Minimal, due in part to low temperature |

**EXHIBIT 3-3: CHARACTERISTICS OF PROTON EXCHANGE MEMBRANE FUEL CELL (UNIT SIZE OF 200–250 KW IN 2001 AND 50-250 KW IN 2010)**

| BENEFIT FACTOR | CHARACTERISTICS |
|---|---|
| Electrolyte | Solid Polymer: perfluorocarbon sulfonic acid ionomer, fluorinated-sulfonic acid polymer, or Nafion® [2, 3, 4, 5] |
| Disadvantages | Smaller module sizes (200–250kW)<br>Relatively complex fuel processing<br>Stack is more sensitive to CO poisoning (requires <10 ppm CO)<br>Requires precious metal catalysts<br>Low temperature requires expensive catalyst (Pt) and is highly sensitive to fuel impurities |

1 http://www.humboldt.edu/~serc/faq.html
2 International Fuel Cell Company (www.ifc.com)
3 Siemens (www.pg.siemens.com)
4 "Opportunities for Micropower and Fuel Cell/Gas Turbine Hybrid Systems in Industrial Applications," Vol. 1, Arthur D. Little, January 2000.
5 "PEM Fuel Cells in Stationary and Mobile Applications," R. Wurster, www.hydrogen.org
6 "EPA Programs Supporting Fuel Cell Implementation," Energy Supply and Industry Branch, U.S. EPA.
7 "State of the Art of Residential Fuel Cells, Market, and Implementation Issues," U.S. EPA Fuel Cell Workshop, Cincinnati, OH, June 26–27, 2001.
8 "DOE Experiences with Fuel Cell Environmental Performance," NETL, U.S. DOE, Strategic Center for Natural Gas.
9 "Fuel Cell Operation on ADG," U.S. EPA Fuel Cell Workshop, Cincinnati, OH, June 26–27, 2001.
10 "EPA Fuel Cell Workshop" presented by Ballard, U.S. EPA Fuel Cell Workshop, Cincinnati OH, June 26–27 2001.

### 3.2.3 Molten Carbonate Fuel Cell (MCFC)

MCFCs are high temperature fuel cells that offer several advantages for onsite or utility-scale power generation. They produce high quality waste heat that can be used for fuel processing and co-generation, internal methane reforming, and conventional production of electricity. The waste heat is of sufficient temperatures to produce high-pressure steam for industrial processes. Developers are targeting commercial markets such as hotels, schools, small to medium sized hospitals, and shopping malls, as well as industrial applications such as chemical, paper, metal, food, and plastics for onsite power generation. The MCFC uses a molten carbonate salt mixture as its electrolyte. The composition of the electrolyte varies, but usually consists of lithium carbonate and potassium carbonate. At the operating temperature of about 1,200°F (650°C), the salt mixture is liquid and provides good ionic conductivity. Exhibit 3-4 below summarizes the main performance characteristics of the MCFC.

**EXHIBIT 3-4: CHARACTERISTICS OF MOLTEN CARBONATE FUEL CELL (UNIT SIZE OF 250–3,000KW IN 2001 AND 250–5,000KW IN 2010)**

| BENEFIT FACTOR | CHARACTERISTICS |
|---|---|
| **TECHNICAL** | |
| Technology Maturity | Research phase |

**EXHIBIT 3-4: CHARACTERISTICS OF MOLTEN CARBONATE FUEL CELL (UNIT SIZE OF 250–3,000KW IN 2001 AND 250–5,000KW IN 2010)**

| BENEFIT FACTOR | CHARACTERISTICS |
|---|---|
| Physical space requirements | Unknown 8'X15' $ft^2$ |
| Infrastructure requirements | Gas hydrocarbon fuel, electric |
| Ease of operation | Unknown |
| Responsiveness/Start-up time | Unknown |
| Co-generation options | Good<br>Operating temperature (ºC): 600–670 [3, 4, 5]<br>High temperature waste heat improves co-generation potential |
| Fuel Efficiency/Quality of power produced | Very high efficiency<br>Electrical Efficiency (LHV, %): 47–60 (55 in 2003–2008) [1, 2, 5, 6]<br>Overall System Efficiency (%): 35–80 [1, 7] |
| Output reliability/consistency | Unknown |
| Fuel flexibility | Natural gas, Methane, Propane, Biogas |
| **ECONOMIC** | |
| Acquisition costs ($/kW) | Not available in 2001.<br>1,000–1,500 in 2010 [1, 3, 5] |
| Annual operation and maintenance (¢/KWh) | Not available in 2001<br>0.5–1.5 in 2010 [1]<br>Quarterly/annual: routine preventative maintenance/inspection<br>5–10 years: stack replacement<br>Remote monitoring/autonomous operation possible[1] |
| Lead time | Unknown, there are no commercially available units |
| Other annual indirect costs (e.g., liability, environmental) | Unknown |
| Service life | 20–30 [1] |

### EXHIBIT 3-4: CHARACTERISTICS OF MOLTEN CARBONATE FUEL CELL (UNIT SIZE OF 250–3,000KW IN 2001 AND 250–5,000KW IN 2010)

| BENEFIT FACTOR | CHARACTERISTICS |
|---|---|
| End-of-life value or cost | Unknown |
| Annual revenue from sale of output | Site specific |
| Annual business energy tax credits/rebates (Federal, State, Local) | May be eligible for grants/tax credits. Programs will vary by State.<br>(Grant of 1,000 $/KW [2] towards purchase possibly available) |
| Emissions credits | None identified |
| **ENVIRONMENTAL** | |
| Air emissions (g/KWh) | $CO_2$: 360–570 @ 35–55% efficiency, 270–310 @ 65–75% efficiency<br>$SO_x$: Negligible (0.001 [5])<br>$NO_x$: Negligible (0.0002 [5]) |
| Wastewater releases | Unknown |
| Solid waste (non-hazardous and hazardous) | Unknown |
| Resource usage (water, fuel, feedstock) | Similar to PAFC |
| Life-Cycle related benefits | Mostly recyclable<br>Very little wear because no moving parts are involved in the power generation process |
| **INSTITUTIONAL** | |
| Regulatory barriers | Needs interconnectivity standards and codes |
| Management/customer acceptance | Not yet demonstrated |
| Staff expertise/training required | Skilled staff needed |
| Advantages | Simpler fuel processing<br>No need for precious metal catalyst due to high operating temp.<br>Stack not sensitive to CO poisoning - Internal reforming due to high operating temp. |
| Disadvantages | Market limited primarily to power generation, reducing overall market potential and potential for cost reduction through mass production<br>Complexity of hybrid cycles<br>Difficult to manufacture |

1 "Opportunities for Micropower and Fuel Cell/Gas Turbine Hybrid Systems in Industrial Applications," Vol. 1, Arthur D. Little, January 2000.
2 www.benwiens.com/energy3.html
3 King County Direct Fuel Cell Project, "On-Site Co-generation using Advanced Fuel Cell Technology," U.S. EPA Analysis of Fuel Cell Applications, June 2001.
4 "Fuel cell Operation on ADG," U.S. EPA Fuel Cell Workshop, Cincinnati, OH, June 26–27, 2001.
5 "DOE Experience with Fuel Cell Environmental Performance," NETL, U.S. DOE, Strategic Center for Natural Gas.
6 Strategic Center for Natural Gas (www.netl.doe.gov/scng)

### 3.2.4 Solid Oxide Fuel Cell (SOFC)

The SOFC uses a ceramic, solid-phase electrolyte which eliminates electrolyte management problems associated with other liquid electrolyte fuel cells. Such a system must operate at about 1,830°F (1,000°C), where internal reforming of carbonaceous fuels should be possible, and the waste heat would be easily utilized by conventional thermal electricity generating plants to yield excellent fuel efficiency. The preferred electrolyte material, dense yttria-stabilized zirconia, is an excellent conductor of negatively charged oxygen (oxide) ions at high temperatures. The SOFC is a solid state device and shares certain properties and fabrication techniques with semi-conductor devices. The anode is a porous nickel/zirconia cermet while the cathode is magnesium-doped lanthanum manganate, or a Sr-doped lanthanum manganite that is a p-type semi-conductor. In operation, hydrogen or carbon monoxide (CO) in the fuel stream reacts with oxide ions ($O^{2-}$) from the electrolyte to produce water or $CO_2$ and to deposit electrons into the anode. The electrons pass outside the fuel cell, through the load, and back to the cathode where oxygen from air receives the electrons and is converted into oxide ions which are injected into the electrolyte. It is significant that the SOFC can use CO as well as hydrogen as its direct fuel. Exhibit 3-5 below summarizes the main performance characteristics of the SOFC.

**EXHIBIT 3-5: CHARACTERISTICS OF SOLID OXIDE FUEL CELL**
**(UNIT SIZE OF 50–5,000 KW IN 2010)**
**(NOT COMMERCIALLY AVAILABLE IN 2001)**

| BENEFIT FACTOR | CHARACTERISTICS |
|---|---|
| **TECHNICAL** | |
| Technology Maturity | Research/bench test phase, field testing, not yet to pilot production |
| Physical Space Requirements | Unknown |
| Infrastructure requirements | Gas hydrocarbon fuel, electric |
| Ease of operation | Solid electrolyte reduces corrosion and management problems |
| Responsiveness/Start-up time | Extended |
| Co-generation options | Good<br>High grade waste heat gives great co-generation potential<br>Operating temperature (EC): 650–1,000 [1, 2, 4] |
| Quality of power produced | Electrical Efficiency (LHV, %): 45–55 (47–63 in 2008, 50–60 in 2010) [1, 3, 4]<br>(70–75% if integrated with a gas turbine) [5]<br>Overall System Efficiency (%): 35–55 [1, 4] |
| Output reliability/consistency | Unknown |

## EXHIBIT 3-5: CHARACTERISTICS OF SOLID OXIDE FUEL CELL (UNIT SIZE OF 50–5,000 KW IN 2010) (NOT COMMERCIALLY AVAILABLE IN 2001)

| BENEFIT FACTOR | CHARACTERISTICS |
|---|---|
| Fuel flexibility | Natural gas, Methane, Propane, Biogas |
| **ECONOMIC** | |
| Acquisition costs ($/kW) | Not available in 2001.<br>1,000–1,500 in 2004–2010 [1, 4]<br>Raw materials cost approx. $15/kW |
| Annual operation and maintenance (¢/KWh) | Not available in 2001.<br>0.5–1.5 in 2010 [1]<br>Quarterly /annual: routine preventative maintenance/inspection<br>5–10 years: stack replacement<br>Remote monitoring/autonomous operation possible[1] |
| Lead time | Unknown |
| Other annual indirect costs (e.g., liability, environmental) | Unknown |
| Service life (years) | 20–30 [1] Dependent primarily on the number of temperature cycles. |
| End-of-life value or cost | Most all recyclable (reformer catalyst, housing, supports)<br>Disposition uncertain for refractory ceramic insulation and fuel cell modules |
| Annual revenue from sale of output | Site specific |
| Annual business energy tax credits/rebates (Federal, State, Local) | May be eligible for grants/tax credits. Programs will vary by State.<br>(Grant of 1,000 $/KW [2] towards purchase possibly available) |
| Emissions credits | None identified |
| **ENVIRONMENTAL** | |
| Air emissions (g/KWh) | $CO_2$: 360–570 @ 35–55% efficiency, 270–310 @ 65–75% efficiency<br>$SO_x$: Negligible<br>$NO_x$: Negligible (0.004–0.008)[1, 4] |
| Wastewater releases | Unknown |
| Solid waste (non-hazardous and hazardous) | None anticipated |
| Resource usage (water, fuel, feedstock) | Similar to PAFC |

### EXHIBIT 3-5: CHARACTERISTICS OF SOLID OXIDE FUEL CELL (UNIT SIZE OF 50–5,000 KW IN 2010) (NOT COMMERCIALLY AVAILABLE IN 2001)

| BENEFIT FACTOR | CHARACTERISTICS |
|---|---|
| Life-Cycle related benefits | Minimal hazardous waste from manufacturing (chromium, arsenic, lead from coating, plating and surface preparation activities)<br>Very little wear because no moving parts are involved in the power generating process |
| **INSTITUTIONAL** | |
| Regulatory barriers | Needs interconnectivity standards and codes |
| Management/customer acceptance | Not yet demonstrated |
| Staff expertise/training required | Skilled staff needed |
| Advantages | Minimal fuel processing (internal reforming)<br>Unique among fuel cells, SOFCs provide a nearly perfect match with small gas turbines<br>Catalysts are rare earths, not Pt |
| Disadvantages | Stringent material requirements for cell components<br>Market limited primarily to power generation, reducing overall market potential<br>Gas sealing is not easy |

1 “Opportunities for Micropower and Fuel Cell/Gas Turbine Hybrid Systems in Industrial Applications,” Vol. 1, Arthur D. Little, January 2000.
2 “Fuel Cell Operation on ADG,” U.S. EPA Fuel Cell Workshop, Cincinnati OH, June 26–27, 2001.
3 “DOE Experiences with Fuel Cell Environmental Performance,” NETL, U.S. DOE, Strategic Center for Natural Gas.
4 http://www.dodfuelcell.com

## 3.3 Comparison of Fuel Cell Characteristics

A comparison of the characteristics for each fuel cell is presented in Exhibit 3-6.

**EXHIBIT 3-6: COMPARISON OF FUEL CELL CHARACTERISTICS**

| | PAFC | PEMFC | SOFC | MCFC |
|---|---|---|---|---|
| **TECHNICAL FACTORS** | | | | |
| Technology maturity | Commercially available | Limited commercial availability | Research phase/bench scale testing | Research phase |
| Physical space requirements | 2,000 $ft^3$ | 3,000 $ft^3$ | Unknown | Unknown |
| Infrastructure requirements | Gas hydrocarbon fuel, electric | Gas hydrocarbon fuel, electric | Gas hydrocarbon fuel, electric | Gas hydrocarbon fuel, electric |
| Start-up time | Rapid | Rapid | Extended | Unknown |
| Co-generation potential | Excellent | Limited | Good | Good |
| Fuel efficiency (electrical output only) | 35–55% efficiency | 35–55% efficiency | 35–55% efficiency | 35–80% efficiency* |
| Output reliability/consistency | 99.9 to 99.9999% | 99.9999% | Unknown | Unknown |
| Fuel flexibility | Natural Gas, Methane, Propane, Biogas | Natural Gas, Methane, Propane, Biogas | Natural Gas, Methane, Propane, Biogas | Natural Gas, Methane, Propane, Biogas |
| **ECONOMIC FACTORS** | | | | |
| Acquisition costs (purchase and installation) ($/KW) | 2,000-4,500 in 2001<br>750–1,000 in 2010 | >10,000 in 2001<br>900–1,500 in 2008 | not available in 2001<br>1,000–1,500 in 2010 | not available in 2001<br>1,000–1,500 in 2010 |
| Annual operation and maintenance costs (cents/KWh) | 1.5–2.0 in 2001<br>0.5–1.5 in 2010 | 1.5–2.0 in 2001<br>0.5–1.5 in 2010 | not available in 2001<br>0.5–1.5 in 2010 | not available in 2001<br>0.5–1.5 in 2010 |
| Other annual indirect costs (e.g., liability, environmental) | $35,000 /year or 2 cents per KWh | Unknown | Unknown | Unknown |
| Lead Time | 16 weeks | Unknown | Unknown | Unknown |
| Service life (years) | 20–30 | 20–30 | 20–30 | 20–30 |
| Annual revenue from sale of output | Site specific | Site specific | Site specific | Site specific |
| Possible energy tax credits/rebates/grants (Federal, State, local) | May be eligible for grants. Programs vary by State. | May be eligible for grants. Programs vary by State. | May be eligible for grants. Programs vary by State. | May be eligible for grants. Programs vary by State. |
| Emissions credits | None identified | None identified | None identified | None identified |

**EXHIBIT 3-6: COMPARISON OF FUEL CELL CHARACTERISTICS**

| | PAFC | PEMFC | SOFC | MCFC |
|---|---|---|---|---|
| **ENVIRONMENTAL FACTORS** | | | | |
| Air emissions (g/KWh) | 360–570 $CO_2$, 0.02 $SO_2$ and NOx | 360–570 $CO_2$, 0.04 $SO_2$ and NOx | 360–570 $CO_2$, negligible $SO_2$ and NOx | 360–570 $CO_2$, 0.001 $SO_2$ and 0.0002 NOx |
| Wastewater production (gal./yr.) | 300 | Unknown | Unknown | Unknown |
| Solid waste (non-hazardous and hazardous) production (lbs./yr.) | 150 | None anticipated | None anticipated | Unknown |
| Resource usage (water, fuel feedstock) | 2,100 $ft^3$ of natural gas per hour or equivalent BTU content of biogas | Similar to PAFC per KWh. | Similar to PAFC per KWh. | Unknown |
| Life-Cycle related benefits | Mostly recyclable, little hazardous waste generated | Mostly recyclable | Minimal hazardous waste | Mostly recyclable |
| **INSTITUTIONAL FACTORS** | | | | |
| Regulatory barriers | Needs standards and codes | Needs standards and codes | Needs standards and codes | Needs standards and codes |
| Market/customer acceptance | High, over 225 units delivered | High acceptance in vehicles | Not yet demonstrated | Not yet demonstrated |
| Staff expertise/training required | Skilled staff needed to maintain gas conditioning and power inversion equipment | Minimal, due in part to low temperature | Unknown — But expect skilled staff to be needed | Unknown — But expect skilled staff to be needed |

* Arthur D. Little, January 2000, and U.S. EPA Fuel Cell Workshop, Cincinnati, OH, June 26–27, 2001.

As a next step, experts carefully reviewed the benefit factors presented earlier in this chapter, and selected from this list, those benefit factors that are the most relevant and could be used to identify industrial sectors having the greatest potential for fuel cell technology. The evaluation of these factors is presented in Chapter 4.0.

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# 4.0 Industry Sector Evaluation and Prioritization

The applicability of a given fuel cell technology to a specific industry sector is based on how well that technology meets the electrical and thermal energy demands for the industry. Chapter 4.0 describes how the industrial sectors in this study were evaluated and prioritized for having the greatest potential for fuel cell technologies. More specifically, Section 4.1 describes the data collection efforts to establish the baseline data used to analyze the industrial sectors. Section 4.2 describes how these baseline data were analyzed against the "selected" benefit factors presented in Chapter 3.0 to prioritize the industry sectors having the greatest potential for fuel cell technologies.

## 4.1 Industry Sector Data Collection

The initial step involved in the screening analysis of industrial markets for fuel cell technologies involved the identification, collection and in some cases, the calculation of baseline data to characterize the electrical and thermal energy demands for industrial sectors as well as the potential availability of product fuel sources. These baseline data provide the information needed to critically evaluate and better understand the potential opportunities for the application of fuel cell technologies in the various industry sectors. A total of 10 data points were collected or derived (See adjacent text box) for each industrial sector to generate the baseline data for the benefit factor analysis. The resulting data relevant to evaluating and "down-selecting" the industrial sectors are included is Exhibit 4-1.

**Data Points Collected to Establish Baseline Data**

1. Number of facilities in targeted industry sector
2a. Total electricity consumption per facility (establishment)
2b. Total electricity consumption for all establishments by employee range
3. Average power demand as electric power consumption per facility
4. Total thermal consumption per facility (establishment)
5. Cost of electricity per kWh for targeted industry sector
6. Compatibility with fuel cell size
7. Total emissions attributed to operation of targeted industry sector
8. Avoided pollution resulting from the use of fuel cells
9. Biogas production potential
10. Overall cost of fuel cells

The data sources and methodology used to derive these baseline values for the number of establishments or facilities comprising the sector, energy usage in terms of quantity and cost, thermal usage, methane production and environmental releases are presented in greater detail below. The data gathered provided the baseline against which to measure potential opportunities for fuel cell technology for each industry sector.

**Data Point 1: Number of facilities in a targeted industry sector**

The 1999 County Business Patterns data developed by the U.S. Census Bureau were the primary source for identifying the number of facilities or establishments in an industry sector. The County Business Patterns provide annual data on the economic activity for an industry as well as the total number of establishments. Establishment is defined as "a single physical location at which business is conducted or services or industrial operations are performed." Facilities are listed by employee ranges (e.g. 1 to 4, 5 to 9, etc.) and provide the total number of establishments that fall within that range nationwide. With the exception of wastewater treatment plants (WWTPs) and the Agriculture sector, all of the establishments were identified using the 1999 County Business Patterns. The total number of establishments identified for WWTPs was taken from the 1996 Clean Water Needs Survey. These data represent establishments that have a wastewater treatment capacity measured in millions of gallons per day (MGD). For the agricultural sectors, the number of establishments was characterized by acres of farm land as opposed to number of employees.

**Data Point 2a: Total electricity consumption per facility (i.e., establishment)**

The total electricity consumed for an entire industry sector is available from the Energy Information Administration (EIA). The data were taken directly from the total electricity consumption for the industry, or derived from the 1995 Commercial Building Energy Consumption Survey (CBECS) that provides general electricity consumption numbers per type of activity. In both cases, the energy consumption per employee was derived as follows:

Electricity consumption per employee = (Total electricity consumption)/(Total number of employees)

The next step involved calculating the average number of employees for each employee range. For each range of establishments, an average number of employees is derived (e.g.,: 2 employees for establishments employing 1 to 4 people). Finally, the electricity consumption per establishment is calculated as follows:

Electricity consumption per establishment = (Average number of employees for a given establishment) X (Electricity consumption per employee)

**Data Point 2b: Total electricity consumption for all establishments having employees within a given range**

This value represents the total amount of electricity consumed over a year by an industry sector. This number is calculated once the electricity consumption per establishment and the total number of facilities having employees within a given range are established. The calculation is as follows:

Total electricity consumption for each range of employees =
(Electricity consumption per establishment) X (Total number of establishments)

**Data Point 3: Average power demand as electric power consumption per facility**

The average power demand represents the amount of instantaneous electricity consumed at any given time per establishment. The average power demand is calculated to correlate with the anticipated output of the fuel cell. It is a way to match the power needed by a facility to the output of the fuel cell. It was calculated assuming that electricity at an establishment is consumed 24 hours a day, 365 days a year without interruption, or (24 X 365 =) 8,760 hrs./yr. All consumption numbers are given per year. The average power demand is calculated as follows:

Average power demand = (Electricity consumption) / (8,760)
The unit of measure for Electricity consumption is Watt-hour while the unit of measure for "Average power demand" is Watt.

**Data Point 4: Total thermal consumption per facility (establishment)**

Total thermal consumption represents the total amount of heat or steam consumed over a year by an industry sector. It is derived by extrapolating the thermal to electric consumption ratio from the CBECS data for the different industry sectors. Data for several industry sectors were assimilated using the CBECS and taking the ratio of thermal consumption to energy consumption as follows:

- Offices comprise Data Facilities, Telecommunications Support and Banking Facilities. For these sectors, 66% of energy consumption is electric and 33% is thermal (a ratio of thermal to electric of 50%).
- Services comprise Logging, Landfills, Military Bases and Agriculture. For these sectors, 52% of energy consumption is electric, 48% in general is thermal (a ratio of thermal to electric of 90%). However, no thermal usage is expected for logging and landfills.
- Health Care facilities comprise Hospitals. For this sector, 38% of energy consumption is electric, 62% is thermal (a ratio of thermal to electric of 163%).
- The Paper Manufacturing industry sector shows a thermal consumption equal to 2.85 times that of electric consumption (285%).
- Lodging comprises Hotels. For that sector, 41% of energy consumption is electric and 59% is thermal (ratio of thermal to electric of 144%).
- Education comprises Educational Services. For that sector, 36% of energy is electrical and 64% thermal (ratio of thermal to electric of 178%).

**Data Point 5: Cost of electricity per kWh for targeted industry sector**

Total electricity cost represents the cost of electricity per kWh of power produced from the grid averaged over the continental U.S. by industry sector. Electricity costs were collected from one of three sources: 1) the 1997 Economic Census, 2) the CBECS, or 3) data sources directly related to the industry sector in question (e.g., 1997 Census of Agriculture).

**Data Point 6: Compatibility with fuel cell size**

Determining the ability of fuel cells to successfully replace the power grid as the main source of electric power is derived by calculating the Average Power Demand at a given facility at any given time. This power demand is then compared to the power output of a fuel cell. If the average power demand falls between 50% and 500% of the capacity of a fuel cell, then that fuel cell is considered a good alternative for power. It is assumed that a fuel cell can be used for applications requiring only 50% of its power output, and that within a facility, potentially five fuel cells can be linked together to produce five times (500%) the power that only one fuel cell would generate. This resulting fuel cell "compatibility range" is obviously dependent upon fuel cell vendors being able to scale up/down their product.

**Data Point 7: Total emissions attributed to the operation of targeted industry sector**

Total emissions represents the total emissions of $CO_2$, $SO_2$ and $NO_x$ generated from grid power sources to met the electricity need. These data are derived from the electricity consumption values and are calculated from national averages (E-Grid Outlook, Energy Information Administration) of typical emissions generated by the grid when producing electricity.

**Data Point 8: Avoided pollution resulting from the use of fuel cells**

The avoided pollution is determined by subtracting the pollution emitted by fuel cells if they were used as a power source instead of the power grid from the pollution emitted by the power grid based on the electricity consumption of a given industry sector. The calculation is as follows:

Avoided pollution = (Pollution emitted by grid) - (Pollution emitted by fuel cells)

**Data Point 9: Biogas production potential**

For selected sectors (Agriculture, Landfills and WWTP's), the production of biogas (e.g., predominantly was calculated using information and data gathered from the EPA Global Warming Site: National Emissions — Methane Emissions http://www.epa.gov/globalwarming/emissions/national/methane.html. The total methane emitted nationwide by one industry sector is subdivided by establishments with different employee sizes, much like the electricity and thermal consumption.

**Data Point 10: Overall cost of fuel cells**

The total overall cost is expressed in cents per kilowatt hour (¢/kWh), and is comprised of the installed costs, the operation and maintenance costs and the fuel costs.

- The installed costs, expressed in dollars per kilowatt ($/kW) of power produced by the fuel cell, is provided by the fuel cell manufacturer and is spread over an assumed lifetime of ten (10) years. Also, in order to convert that cost to ¢/kWh, an operation time of 24 hours per day, 365 days per year, or a total of 8,760 hours per year was assumed.

- Cost per kW/ 8,760 hrs = cost per kWh.

C Operation and maintenance were expressed by the manufacturer directly in ¢/kWh.

C Fuel costs were calculated assuming a typical natural gas fuel consumption of 1,900 $ft^3$/hour (per 200 kWh, Table 3-2), an operation of 8,760 hours per year, and a natural gas cost of $5.35 per thousand cubic feet (tcf) in 2001 and $4.38 per tcf in 2010 (EIA).

Once the installation costs, operation and maintenance costs, and fuel costs are calculated in ¢/kWh, they were summed to derive the total cost.

Exhibits 4-1 and 4-2 below present the resulting data using the data collection and calculation methods presented above both for the years 2001 and 2010. For each industry sector, these data include the facility size range, number of establishments, electricity costs, pollution produced by electricity generation, energy (electricity and thermal) consumption, and biogas emissions (these biogases can potentially be used as a fuel for fuel cells).

**EXHIBIT 4-1: INDUSTRY-LEVEL ASSESSMENT OF EVALUATION FACTOR (2001)**

| INDUSTRY SECTOR | ESTABLISH-MENT SIZE RANGE (NO. OF EMPLOYEES) | NUMBER OF ESTABLISH-MENTS | ELECTRICITY COST (¢/kWh) | TOTAL EMISSIONS (MILLION lbs./yr) | TOTAL ELECTRICITY CONSUMPTION (MWh) | TOTAL THERMAL CONSUMPTION (MWh) | TOTAL BIOGAS PRODUCED (METRIC TON) |
|---|---|---|---|---|---|---|---|
| Agriculture-Livestock* | 1–9 | 84,059 | 7.0 | 227 | 158,928 | 139,857 | 34,758 |
| | 10–49 | 224,957 | | 3,653 | 2,551,915 | 2,245,685 | 558,108 |
| | 50–99 | 161,549 | | 6,558 | 4,581,539 | 4,031,755 | 1,001,991 |
| | 100–179 | 163,140 | | 12,362 | 8,636,444 | 7,600,071 | 1,888,806 |
| | 180–499 | 220,541 | | 40,585 | 28,354,013 | 24,951,531 | 6,201,075 |
| | 500–2000+ | 192,616 | | 130,318 | 91,043,383 | 80,118,177 | 19,911,355 |
| | Total | 1,046,863 | | 193,703 | 135,326,221 | 119,087,075 | 29,596,093 |
| Banking Facilities | <20 | 1,054 | 7.1 | 110 | 76,942 | 38,471 | 0 |
| | 20–49 | 99 | | 36 | 25,295 | 12,647 | 0 |
| | 50–99 | 50 | | 39 | 27,375 | 13,688 | 0 |
| | 100+ | 137 | | 787 | 550,055 | 275,028 | 0 |
| | Total | 1,340 | | 973 | 679,667 | 339,833 | 0 |
| Computer/ Data Facilities | 1–4 | 4,989 | 7.1 | 104 | 72,839 | 36,420 | 0 |
| | 5–9 | 1,053 | | 77 | 53,808 | 26,904 | 0 |
| | 10–19 | 868 | | 136 | 95,046 | 47,523 | 0 |
| | 20–49 | 936 | | 342 | 239,148 | 119,574 | 0 |
| | 50–249 | 840 | | 1,317 | 919,800 | 459,900 | 0 |
| | 250–1000+ | 228 | | 1,489 | 1,040,250 | 520,125 | 0 |
| | Total | 8,914 | | 3,465 | 2,420,892 | 1,210,446 | 0 |
| Educational Services | 1–4 | 31,215 | 8.0 | 2,380 | 1,662,889 | 2,959,943 | 0 |
| | 5–9 | 10,577 | | 2,823 | 1,972,108 | 3,510,351 | 0 |
| | 10–19 | 8,864 | | 5,069 | 3,541,531 | 6,303,925 | 0 |
| | 20–49 | 9,057 | | 12,086 | 8,443,499 | 15,029,428 | 0 |
| | 50+ | 6,779 | | 12,923 | 9,028,294 | 16,070,363 | 0 |
| | Total | 66,492 | | 35,281 | 24,648,321 | 43,874,011 | 0 |
| Hospitals | <20 | 336 | 6.3 | 69 | 48,182 | 78,537 | 0 |
| | 20–99 | 768 | | 946 | 660,787 | 1,077,083 | 0 |
| | 100–499 | 3,040 | | 18,720 | 13,078,080 | 21,317,270 | 0 |
| | 500+ | 2,816 | | 40,460 | 28,267,008 | 46,075,223 | 0 |
| | Total | 6,960 | | 60,195 | 42,054,057 | 68,548,113 | 0 |
| Landfills | 1–4 | 595 | 7.8 | 15 | 10,489 | 0 | 468,546 |
| | 5–9 | 325 | | 29 | 20,053 | 0 | 895,749 |
| | 10–19 | 284 | | 54 | 37,550 | 0 | 1,677,315 |
| | 20–49 | 201 | | 89 | 62,011 | 0 | 2,769,933 |
| | 50–99 | 70 | | 66 | 46,277 | 0 | 2,067,114 |
| | 100–1000+ | 40 | | 278 | 193,921 | 0 | 8,662,192 |
| | Total | 1,515 | | 530 | 370,301 | 0 | 16,540,850 |

**EXHIBIT 4-1: INDUSTRY-LEVEL ASSESSMENT OF EVALUATION FACTOR (2001)**

| INDUSTRY SECTOR | ESTABLISH-MENT SIZE RANGE (NO. OF EMPLOYEES) | NUMBER OF ESTABLISH-MENTS | ELECTRICITY COST (¢/kWh) | TOTAL EMISSIONS (MILLION lbs./yr) | TOTAL ELECTRICITY CONSUMPTION (MWh) | TOTAL THERMAL CONSUMPTION (MWh) | TOTAL BIOGAS PRODUCED (METRIC TON) |
|---|---|---|---|---|---|---|---|
| Logging | 1–4 | 7,791 | 5.5 | 67 | 46,701 | 0 | 0 |
| | 5–9 | 3,009 | | 90 | 63,128 | 0 | 0 |
| | 10–19 | 1,586 | | 102 | 71,302 | 0 | 0 |
| | 20–99 | 602 | | 155 | 108,256 | 0 | 0 |
| | 100–999 | 23 | | 54 | 37,914 | 0 | 0 |
| | Total | 13,011 | | 468 | 327,301 | 0 | 0 |
| Military Bases | 1,518,224 | 466 | 7.3 | 19,155 | 13,382,537 | 11,776,633 | 0 |
| Paper Manufacturing | 1–19 | 12 | 4.1 | 94 | 66,013 | 187,816 | 0 |
| | 20–99 | 160 | | 7,063 | 4,934,539 | 14,039,442 | 0 |
| | 100–499 | 236 | | 56,321 | 39,347,563 | 111,949,216 | 0 |
| | 500–999 | 89 | | 47,660 | 33,296,356 | 94,732,701 | 0 |
| | 1000+ | 52 | | 35,500 | 24,801,384 | 70,563,342 | 0 |
| | Total | 549 | | 146,639 | 102,445,855 | 291,472,517 | 0 |
| Telecommunications Support | 1–4 | 18,597 | 7.1 | 389 | 271,516 | 135,758 | 0 |
| | 5–9 | 5,729 | | 419 | 292,752 | 146,376 | 0 |
| | 10–19 | 4,501 | | 705 | 492,860 | 246,430 | 0 |
| | 20–49 | 4,005 | | 1,465 | 1,023,278 | 511,639 | 0 |
| | 50–99 | 1,955 | | 1,532 | 1,070,363 | 535,181 | 0 |
| | 100–1000+ | 2,155 | | 12,385 | 8,652,325 | 4,326,163 | 0 |
| | Total | 36,942 | | 16,895 | 11,803,093 | 5,901,546 | 0 |
| Traveler Accommodations | 1–4 | 18,589 | 7.0 | 1,730 | 1,208,911 | 1,765,011 | 0 |
| | 5–9 | 6,481 | | 2,112 | 1,475,192 | 2,153,780 | 0 |
| | 10–19 | 9,639 | | 6,730 | 4,701,449 | 6,864,115 | 0 |
| | 20–49 | 8,564 | | 13,951 | 9,746,601 | 14,230,037 | 0 |
| | 50+ | 5,689 | | 13,239 | 9,249,418 | 13,504,150 | 0 |
| | Total | 48,962 | | 37,762 | 26,381,571 | 38,517,093 | 0 |
| WWTPs** | 1 | 2,151 | 7.0 | 1,247 | 871,155 | 107,059 | 18,480 |
| | 2.5 | 482 | | 489 | 341,497 | 267,648 | 10,352 |
| | 5 | 337 | | 681 | 475,979 | 535,297 | 14,476 |
| | 10 | 213 | | 1,322 | 923,888 | 1,070,594 | 18,299 |
| | 20 | 161 | | 1,509 | 1,054,550 | 2,141,188 | 27,664 |
| | 50 | 58 | | 1,169 | 816,930 | 5,352,969 | 24,915 |
| | 100 | 50 | | 3,089 | 2,158,000 | 10,705,938 | 42,956 |
| | Total | 3,452 | | 9,507 | 6,641,999 | 20,180,693 | 157,143 |

*Number of acres
** Million Gallon per Day (MGD)

Growth factors were identified for each industry sector to project the number of establishments, associated electricity costs, pollution produced by electricity generation, electricity and thermal consumption, and biogas emissions for 2010. The data resulting from the application of the growth factors presented below are included in Exhibit 4-2.

| | |
|---|---|
| Agriculture-Livestock— | A 0% annual growth rate was assumed through 2010 based on the 1992–1997 Census of Agriculture data indicating a 0.15% decrease over five years. |
| Banking Facilities— | An annual growth rate of 0% was used based on CBP data indicating a slight decrease over the last two years. |
| Computer/Data Facilities— | An annual growth rate of 7% was used based on CBP data indicating a 7% increase in computer/data facilities over the last two years. |
| Educational Services— | An annual growth rate of 3.4% was used based on CBP data indicating a 3.4% average annual increase in educational facilities over the last six years. |
| Hospitals— | A 1% annual growth rate was applied based on CBP data indicating a 0.1% increase of in-patient care facilities over the last two years and a 2.9% increase (as a projection) in the electricity consumption of hospitals, based on EIA's Annual Energy Outlook 2001. |
| Landfills— | A 0% annual growth rate was used, based on CBP data indicating a slight decrease over the last two years. |
| Logging— | An annual growth rate of 0% was used based on CBP data indicating a slight decrease in logging facilities over the last two years. |
| Military Bases— | A 0% annual growth rate was applied based on general perceptions that the military sector in the U.S. would not grow in size over the next ten years. |
| Paper Manufacturing— | An annual growth rate of 0% was used based on lack of appropriate data. |
| Traveler Accommodations— | A 1.6% annual growth rate was used based on CBP data indicating a 1.6% average annual increase over the last six years. |

Telecommunications Support— An annual growth rate of 9.5% was used based on CBP data indicating a 9.5% average annual increase over the last two years.

WWTPs— An annual growth rate of 2% was applied to WWTP facilities.

**EXHIBIT 4-2: INDUSTRY-LEVEL ASSESSMENT OF EVALUATION FACTOR (2010)**

| INDUSTRY SECTOR | ESTABLISH-MENT SIZE RANGE | NUMBER OF ESTABLISH-MENTS | ELECTRICITY COST (¢/kWh) | TOTAL EMISSIONS (MILLION lbs./yr) | TOTAL ELECTRICITY CONSUMPTION (MWh) | TOTAL THERMAL CONSUMPTION (MWh) | TOTAL BIOGAS PRODUCED (METRIC TON) |
|---|---|---|---|---|---|---|---|
| Agriculture-Livestock* | 1–9 | 84,059 | 7.0 | 227 | 158,928 | 139,857 | 34,758 |
| | 10–49 | 224,957 | | 3,653 | 2,551,915 | 2,245,685 | 558,108 |
| | 50–99 | 161,549 | | 6,558 | 4,581,539 | 4,031,755 | 1,001,991 |
| | 100–179 | 163,140 | | 12,362 | 8,636,444 | 7,600,071 | 1,888,806 |
| | 180–499 | 220,541 | | 40,585 | 28,354,013 | 24,951,531 | 6,201,075 |
| | 500–2000+ | 192,616 | | 130,318 | 91,043,383 | 80,118,177 | 19,911,355 |
| | Total | 1,046,863 | | 193,703 | 135,326,221 | 119,087,075 | 29,596,093 |
| Banking Facilities | <20 | 1,054 | 7.1 | 110 | 76,942 | 38,471 | 0 |
| | 20–49 | 99 | | 36 | 25,295 | 12,647 | 0 |
| | 50–99 | 50 | | 39 | 27,375 | 13,688 | 0 |
| | 100+ | 137 | | 787 | 550,055 | 275,028 | 0 |
| | Total | 1,340 | | 973 | 679,667 | 339,833 | 0 |
| Computer Data Facilities | 1–4 | 9,813 | 7.1 | 205 | 143,275 | 71,638 | 0 |
| | 5–9 | 2,071 | | 151 | 105,841 | 52,920 | 0 |
| | 10–19 | 1,707 | | 268 | 186,955 | 93,478 | 0 |
| | 20–49 | 1,841 | | 673 | 470,404 | 235,202 | 0 |
| | 50–249 | 1,652 | | 2,590 | 1,809,247 | 904,623 | 0 |
| | 250–1000+ | 448 | | 2,929 | 2,046,172 | 1,023,086 | 0 |
| | Total | 17,534 | | 6,816 | 4,761,894 | 2,380,947 | 0 |
| Educational Services | 1–4 | 43,607 | 8.0 | 3,325 | 2,323,057 | 4,135,041 | 0 |
| | 5–9 | 14,776 | | 3,944 | 2,755,034 | 4,903,961 | 0 |
| | 10–19 | 12,383 | | 7,082 | 4,947,519 | 8,806,583 | 0 |
| | 20–49 | 12,653 | | 16,884 | 11,795,568 | 20,996,111 | 0 |
| | 50+ | 9,470 | | 18,053 | 12,612,526 | 22,450,297 | 0 |
| | Total | 92,889 | | 49,288 | 34,433,704 | 61,291,993 | 0 |
| Hospitals | <20 | 371 | 6.3 | 76 | 53,223 | 86,754 | 0 |
| | 20–99 | 848 | | 1,045 | 729,920 | 1,189,770 | 0 |
| | 100–499 | 3,358 | | 20,678 | 14,446,337 | 23,547,529 | 0 |
| | 500+ | 3,111 | | 44,694 | 31,224,362 | 50,895,711 | 0 |
| | Total | 7,688 | | 66,493 | 46,453,842 | 75,719,764 | 0 |

**EXHIBIT 4-2: INDUSTRY-LEVEL ASSESSMENT OF EVALUATION FACTOR (2010)**

| INDUSTRY SECTOR | ESTABLISH-MENT SIZE RANGE | NUMBER OF ESTABLISH-MENTS | ELECTRICITY COST (¢/kWh) | TOTAL EMISSIONS (MILLION lbs./yr) | TOTAL ELECTRICITY CONSUMPTION (MWh) | TOTAL THERMAL CONSUMPTION (MWh) | TOTAL BIOGAS PRODUCED (METRIC TON) |
|---|---|---|---|---|---|---|---|
| Landfills | 1–4 | 595 | 7.8 | 15 | 10,489 | 0 | 468,546 |
| | 5–9 | 325 | | 29 | 20,053 | 0 | 895,749 |
| | 10–19 | 284 | | 54 | 37,550 | 0 | 1,677,315 |
| | 20–49 | 201 | | 89 | 62,011 | 0 | 2,769,933 |
| | 50–99 | 70 | | 66 | 46,277 | 0 | 2,067,114 |
| | 100–1000+ | 40 | | 278 | 193,921 | 0 | 8,662,192 |
| | Total | 1,515 | | 530 | 370,301 | 0 | 16,540,850 |
| Logging | 1–4 | 7,791 | 5.5 | 67 | 46,701 | 0 | 0 |
| | 5–9 | 3,009 | | 90 | 63,128 | 0 | 0 |
| | 10–19 | 1,586 | | 102 | 71,302 | 0 | 0 |
| | 20–99 | 602 | | 155 | 108,256 | 0 | 0 |
| | 100–999 | 23 | | 54 | 37,914 | 0 | 0 |
| | Total | 13,011 | | 468 | 327,301 | 0 | 0 |
| Military Bases | 1,518,224 | 466 | 7.3 | 19,155 | 13,382,537 | 11,776,633 | 0 |
| Paper Manufact-uring | 1–19 | 12 | 4.1 | 94 | 66,013 | 187,816 | 0 |
| | 20–99 | 160 | | 7,063 | 4,934,539 | 14,039,442 | 0 |
| | 100–499 | 236 | | 56,321 | 39,347,563 | 111,949,216 | 0 |
| | 500–999 | 89 | | 47,660 | 33,296,356 | 94,732,701 | 0 |
| | 1000+ | 52 | | 35,500 | 24,801,384 | 70,563,342 | 0 |
| | Total | 549 | | 146,639 | 102,445,855 | 291,472,517 | 0 |
| Telecomm-unications Support | 1–4 | 46,083 | 7.1 | 963 | 672,817 | 336,409 | 0 |
| | 5–9 | 14,196 | | 1,038 | 725,439 | 362,720 | 0 |
| | 10–19 | 11,153 | | 1,748 | 1,221,306 | 610,653 | 0 |
| | 20–49 | 9,924 | | 3,630 | 2,535,682 | 1,267,841 | 0 |
| | 50–99 | 4,844 | | 3,797 | 2,652,358 | 1,326,179 | 0 |
| | 100–1000+ | 5,340 | | 30,689 | 21,440,461 | 10,720,231 | 0 |
| | Total | 91,542 | | 41,865 | 29,248,063 | 14,624,032 | 0 |
| Traveler Accommod-ations | 1–4 | 21,786 | 7.0 | 2,028 | 1,416,844 | 2,068,593 | 0 |
| | 5–9 | 7,596 | | 2,475 | 1,728,925 | 2,524,230 | 0 |
| | 10–19 | 11,297 | | 7,887 | 5,510,098 | 8,044,743 | 0 |
| | 20–49 | 10,037 | | 16,351 | 11,423,016 | 16,677,603 | 0 |
| | 50+ | 6,668 | | 15,517 | 10,840,318 | 15,826,864 | 0 |
| | Total | 57,383 | | 44,257 | 30,919,201 | 45,142,033 | 0 |

**EXHIBIT 4-2: INDUSTRY-LEVEL ASSESSMENT OF EVALUATION FACTOR (2010)**

| INDUSTRY SECTOR | ESTABLISH-MENT SIZE RANGE | NUMBER OF ESTABLISH-MENTS | ELECTRICITY COST (¢/kWh) | TOTAL EMISSIONS (MILLION lbs./yr) | TOTAL ELECTRICITY CONSUMPTION (MWh) | TOTAL THERMAL CONSUMPTION (MWh) | TOTAL BIOGAS PRODUCED (METRIC TON) |
|---|---|---|---|---|---|---|---|
| WWTPs** | 1 | 2,622 | 7.0 | 1,520 | 1,061,933 | 130,505 | 22,527 |
| | 2.5 | 588 | | 596 | 416,283 | 326,263 | 12,620 |
| | 5 | 411 | | 831 | 580,216 | 652,527 | 17,647 |
| | 10 | 260 | | 1,612 | 1,126,214 | 1,305,054 | 22,307 |
| | 20 | 196 | | 1,840 | 1,285,491 | 2,610,108 | 33,722 |
| | 50 | 71 | | 1,425 | 995,833 | 6,525,269 | 30,371 |
| | 100 | 61 | | 3,765 | 2,630,590 | 13,050,538 | 52,364 |
| | Total | 4,209 | | 11,589 | 8,096,560 | 24,600,265 | 191,557 |

*Number of acres
** Million Gallons per Day (MGD)
Total Emissions is based on electricity generation mix in 2001.

WWTPs, landfills and the agriculture sectors, all generate biogas containing methane which can be used as a fuel source for the fuel cells. It is important to quantify the net difference between biogas produced by those industry sectors, and the biogas used as fuel by the fuel cells.

## 4.2 Industry Sector Evaluation and Prioritization

The baseline data presented in Section 4.1 were analyzed using a four-step process to rank and "down-select" the 12 industry sectors to those industrial sectors with the greatest opportunities to utilize fuel cell technologies. The data and the four steps used to prioritize the data are presented below.

### Step 1: Identify Overall Fuel Cell Performance Specifications

The information on the four fuel cell technologies presented in Chapter 3.0 was used to develop Exhibit 4-3 which describes the overall fuel cell performance specifications for PAFC, PEMFC, SOFC, and MCFC technologies. The fuel cell performance specifications were used to determine the compatible energy needs for each industry sector. Exhibit 4-3 presents the cost to generate electricity in 2001 and 2010 for each fuel cell, the unit size, the amount of electricity the unit produces, and total emissions generated (predominantly $CO_2$). In 2001 the PEMFC technology had the highest cost per kilowatt hour at 18.25 ¢/kWh. However, the data indicate that by 2010, the cost of electricity for PEMFC will decrease by 64%. In addition, the cost of the other fuel cell technologies will decrease in average well over 50%. These decreases are mostly attributable to anticipated equipment cost reductions as estimated by fuel cell vendors.

**EXHIBIT 4-3: FUEL CELL SPECIFICATIONS**

| | COST ( 2001, ¢/kWh)* | COST (2010, ¢/kWh)* | ANTICIPATED UNIT SIZES IN 2010 (KW) | ELECTRICITY PRODUCTION PER UNIT IN 2010** (MWh/yr) | EMISSIONS RATE IN 2010*** (GRAMS/kWh) |
|---|---|---|---|---|---|
| **PAFC** | 9.68 | 6.16 | 50–250 | 430–2,200 | 360–570 |
| **PEMFC** | 18.25 | 6.53 | 50–250 | 430–2,200 | 360–570 |
| **SOFC** | 18.00 | 6.59 | 50–5,000 | 430–43,800 | 360–570 |
| **MCFC** | 15.71 | 6.59 | 250–5,000 | 2,200–43,800 | 360–570 |

*These costs take into account acquisition, installation, operation and maintenance and fuel
**Assuming full generating output throughout the year
***Majority of the emissions (>99.9%) are $CO_2$

### Step 2: Develop Fuel Cell Performance and Industry Sector Compatibility Factor

As indicated in Chapter 3.0, the applicability of a given fuel cell technology to a specific industry is based on how well that technology meets the energy demands (electrical and thermal) for the industry. Chapter 3.0 presented benefit factors that were used for two purposes: 1) factors that allow for the comparison of fuel cell technologies to one another, and 2) factors that help evaluate the feasibility of implementing fuel cell technologies within a particular industry. The fuel cell research presented in Chapter 3.0 resulted in the development of a list of factors both quantitative and qualitative to help characterize and compare the technical, economic, environmental, and institutional benefits/merits of fuel cell technologies. Expert judgement was used to identify and select those benefit factors that could then be used to evaluate the feasibility of integrating fuel cell technology within a specific industry sector. The evaluation factors identified as being the most critical and having the greatest relevance in determining the successful implementation of fuel cell technologies within a given industry were: Number of Establishments, Fuel Cell Compatibility, Electricity Cost, Total Emissions, Total Electricity Usage, Total Thermal Usage, and Total Biogas Production. These evaluation factors are included in Exhibits 4-4 and 4-5.

As the second step, a matrix was developed to evaluate fuel cell technologies against the energy demands of the industrial sectors. Using data from Exhibits 4-1, 4-2 and 4-3, the industry sectors were compared to the fuel cells' performance specifications, and a fuel cell compatibility factor was determined. The fuel cell compatibility factor represents the number of facilities that could use a fuel cell as the main onsite source of power within each industry sector. It also represents the ability of fuel cells to successfully replace the power grid as the main source of electric power. This compatibility factor was determined first by calculating the Average Power Demand for a facility at any given time. This power demand is then compared to the power output of a fuel cell. If the average power demand falls between 50% and 500% of the capacity of a fuel cell system, then that fuel cell is considered a good alternative for power. It is assumed that a fuel cell can be used for applications requiring only 50% of its power output, and that within a facility, five fuel cells systems can be linked together to produce five times (500%) the power only one fuel cell would generate.

A fuel cell compatibility factor was developed for 2001 and for 2010. The fuel cell power output for the present time (2001) has been demonstrated by manufacturers: the 2010 figures are based on the manufacturers' projections. The overall power output of fuel cells in 2010 range from 50 kW to 5000 kW.

The compatibility factor column in Exhibit 4-4 is subdivided into two columns. The value in the left column represents the percentage of the industry establishments that could use a fuel cell as the main onsite source of power. The value in the right column represents the comparative rank.

### Step 3: Normalize and Rank the Industry Sectors for each Evaluation Factor

Once the compatibility factor was developed, the remaining evaluation factors were calculated using data for 2001 (Exhibit 4-4) and projected for 2010 (Exhibit 4-5). Each evaluation factor in Exhibit 4-4 and 4-5 is subdivided into two columns.

The normalized value in the left column is a calculation of the percentage contributed by a given industry sector compared to the total contributions of all industrial sectors. The ranking of the evaluation factors was developed by taking the percentage of the sum total of the specific columns (e.g., percentage of the total number of establishments for all industries). For example, in the case of number of establishments, the normalized value of 0.847 is derived by dividing the total number of agricultural establishments (See Exhibits 4-1 and 4-2) 1,046,863 by the total number of establishments for all industrial sectors (1,235,466).

The second column (right column) presents the rank of the industry. For example, the Agricultural industry is assigned a rank of 1 since it is the largest contributing sector presenting the number of establishments. The same calculation is performed for Fuel Cell Compatibility, Electricity Costs, Total Emissions, Total Thermal Consumption and Total Biogas Produced. Note that the rankings for Total Emissions and Total Electricity are the same. This is because the values are dependent given the fact that emissions are calculated based on the electricity consumed. Consequently, only one of them is included in the overall ranking. Exhibit 4-4 and Exhibit 4-5 present the results of this ranking step. The rankings in Exhibit 4-5 are used to down-select those industry sectors with the greatest potential for utilizing fuel cell technologies.

### EXHIBIT 4-4: RANKING OF EVALUATION FACTORS (2001)

| INDUSTRY SECTOR | NUMBER OF ESTABLISH-MENTS | | FUEL CELL COMPATIBILITY (2001) | | ELECTRICITY COST | | TOTAL EMISSIONS (MILLION lbs./yr) | | TOTAL ELECTRICITY CONSUMPTION (MWh) | | TOTAL THERMAL CONSUMPTION (MWh) | | TOTAL BIOGAS PRODUCED (METRIC TONS) | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Agriculture-Livestock | 0.847 | 1 | 0.719 | 1 | 0.086 | 7 | 0.371 | 1 | 0.371 | 1 | 0.200 | 2 | 0.499 | 1 |
| Banking Facilities | 0.001 | 9 | 0.001 | 8 | 0.087 | 4 | 0.002 | 10 | 0.002 | 10 | 0.001 | 10 | 0 | 4 |
| Computer/ Data Facilities | 0.007 | 6 | 0.007 | 7 | 0.087 | 4 | 0.007 | 9 | 0.007 | 9 | 0.002 | 9 | 0 | 4 |
| Educational Services | 0.054 | 2 | 0.092 | 3 | 0.098 | 1 | 0.068 | 5 | 0.068 | 5 | 0.074 | 4 | 0 | 4 |
| Hospitals | 0.006 | 7 | 0.025 | 5 | 0.078 | 10 | 0.115 | 3 | 0.115 | 3 | 0.115 | 3 | 0 | 4 |
| Landfills | 0.001 | 9 | 0.000 | 9 | 0.096 | 2 | 0.001 | 11 | 0.001 | 11 | 0.000 | 11 | 0.493 | 2 |
| Logging | 0.011 | 5 | 0.000 | 9 | 0.068 | 11 | 0.001 | 11 | 0.001 | 11 | 0.000 | 11 | 0 | 4 |
| Military Bases | 0.000 | 11 | 0.000 | 9 | 0.090 | 3 | 0.037 | 6 | 0.037 | 6 | 0.020 | 7 | 0 | 4 |
| Paper Manufacturing | 0.000 | 11 | 0.000 | 9 | 0.050 | 12 | 0.277 | 2 | 0.277 | 2 | 0.481 | 1 | 0 | 4 |
| Telecommuni-cations Support | 0.030 | 4 | 0.030 | 4 | 0.087 | 4 | 0.032 | 7 | 0.032 | 7 | 0.010 | 8 | 0 | 4 |
| Traveler Accommo-dations | 0.040 | 3 | 0.113 | 2 | 0.086 | 7 | 0.072 | 4 | 0.072 | 4 | 0.065 | 5 | 0 | 4 |
| WWTP's | 0.003 | 8 | 0.012 | 6 | 0.086 | 7 | 0.018 | 8 | 0.018 | 8 | 0.034 | 6 | 0.008 | 3 |

Note: As the rankings for Total Emissions and Total Electricity Consumption are the same, only one was included in the overall ranking.

### EXHIBIT 4-5: RANKING OF EVALUATION FACTORS (2010)

| INDUSTRY SECTOR | NUMBER OF ESTABLISH-MENTS | | FUEL CELL COMPATIBILITY (2010) | | ELECTRICITY COST | | TOTAL EMISSIONS (MILLION lbs./yr) | | TOTAL ELECTRICITY CONSUMPTION (MWh) | | TOTAL THERMAL CONSUMPTION (MWh) | | TOTAL BIOGAS PRODUCED (METRIC TONS) | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Agriculture-Livestock | 0.784 | 1 | 0.756 | 1 | 0.086 | 7 | 0.333 | 1 | 0.333 | 1 | 0.064 | 7 | 0.499 | 1 |
| Banking Facilities | 0.001 | 9 | 0.001 | 8 | 0.087 | 4 | 0.002 | 10 | 0.002 | 10 | 0.009 | 10 | 0 | 4 |
| Computer/ Data Facilities | 0.013 | 5 | 0.004 | 7 | 0.087 | 4 | 0.012 | 9 | 0.012 | 9 | 0.034 | 9 | 0 | 4 |
| Educational Services | 0.070 | 2 | 0.097 | 2 | 0.098 | 1 | 0.085 | 4 | 0.085 | 4 | 0.090 | 3 | 0 | 4 |
| Hospitals | 0.006 | 7 | 0.026 | 4 | 0.077 | 10 | 0.114 | 3 | 0.114 | 3 | 0.112 | 2 | 0 | 4 |
| Landfills | 0.001 | 9 | 0.000 | 10 | 0.096 | 2 | 0.001 | 11 | 0.001 | 11 | 0.000 | 11 | 0.493 | 2 |
| Logging | 0.010 | 6 | 0.000 | 10 | 0.068 | 11 | 0.001 | 11 | 0.001 | 11 | 0.000 | 11 | 0 | 4 |
| Military Bases | 0.000 | 11 | 0.001 | 8 | 0.090 | 3 | 0.033 | 7 | 0.033 | 7 | 0.056 | 8 | 0 | 4 |
| Paper Manufacturing | 0.000 | 11 | 0.000 | 10 | 0.050 | 12 | 0.252 | 2 | 0.252 | 2 | 0.426 | 1 | 0 | 4 |
| Telecommuni-cations Support | 0.069 | 3 | 0.016 | 5 | 0.087 | 4 | 0.072 | 6 | 0.072 | 6 | 0.073 | 4 | 0 | 4 |
| Traveler Accommod-ations | 0.043 | 4 | 0.094 | 3 | 0.086 | 7 | 0.076 | 5 | 0.076 | 5 | 0.066 | 6 | 0 | 4 |
| WWTP's | 0.003 | 8 | 0.005 | 6 | 0.086 | 7 | 0.020 | 8 | 0.020 | 8 | 0.070 | 5 | 0.008 | 3 |

Note: As the rankings for Total Emissions and Total Electricity Consumption are the same, only one was included in the overall ranking.

### Step 4: Array and Prioritize Industry Sectors

**Industry Sector Prioritization**

Tier I – Industry sectors best suited for fuel cell technologies.

Tier II – Industry sectors that offer good opportunities for fuel cell technologies but require other incentives.

Tier III – Limited opportunities for implementing fuel cell technologies.

The final step involved an analysis of the evaluation factors calculated for each industry sector in Step 3 using Exhibit 4-5, Ranking of Evaluation Factors 2010. A combination of quantitative analysis and expert judgement was used to array the industry sectors. The quantitative rankings from the previous step were used to prioritize and group industrial sectors into one of three tiers that represent the industrial sectors most compatible, and most likely to benefit from fuel cell technologies. Within each evaluation factor, industries were ranked from 1 to 12. Expert/professional judgement was then used to assess and group the ranked industry sectors. Industrial sectors with the greatest number of evaluation factors receiving high rankings, between 1 and 4, were grouped into Tier 1. This first tier represents those industries best suited for fuel cell technologies. These sectors could utilize fuel cells as an alternative power source with the greatest environmental and economic benefits. Those sectors with a majority of evaluation factors ranking between 9 and 11 were grouped into the lowest tier, Tier III, because few market opportunities for fuel cell technologies were likely. Sectors with a majority of evaluation factors ranking between 5 and 8 were included in Tier II. These industrial sectors, while promising, were not the best candidates. Although still viable for fuel cell implementation, they would require some additional incentives either in the form of tax deductions or other such initiatives.

Although the prioritization steps rank the Paper Manufacturing as having the greatest potential for fuel cell technology in 2001 and 2010, this industry sector does not represent a good opportunity for fuel cell implementation because in 2001 the electricity costs at paper manufacturing plants are notoriously and significantly lower than those of a fuel cell. Therefore, it is economically unprofitable to attempt the utilization of fuel cells as an alternative to the power grid for primary power.

Based on this analysis, the industry sectors representing the best opportunity for fuel cell implementation are presented in Exhibit 4-6.

**EXHIBIT 4-6: RECOMMENDED INDUSTRY PRIORITIZATION FOR FUEL CELL IMPLEMENTATION**

| FIRST TIER |
|---|
| Agriculture-Livestock |
| Educational Services |
| Hospitals |
| Traveler Accommodations |
| Telecommunications Support |
| **SECOND TIER** |
| Banking Facilities |
| Computer/Data Facilities |
| Landfills |
| Military Bases |
| Wastewater Treatment Plants (WWTPs)* |
| **THIRD TIER** |
| Logging |
| Paper Manufacturing |

*Note: The wastewater treatment plant (WWTP) industry sector was elevated to Tier 1 in part due to its high priority interest to the U.S. Environmental Protection Agency, a sponsor of this research.

Additional data such as the pollution avoided, the fuel conserved and the financial savings associated with using fuel cells were also calculated. However, the resulting data were not used to prioritize or down select the most promising sectors for fuel cell technologies and are not included in this chapter. These data were extremely valuable and provided useful information to further characterize the industrial sectors. This detailed information is presented for each Tier I industry sector in the chapter specific to the industry. The methodology used to derive these values and the resulting data tables for the remaining industry sectors is included in Appendix B of this report.

## 4.3 Summary of Findings

The methodology used to "down-select" the original 12 industries identified the Agriculture, Educational Services (Educational Facilities), Hospitals, Traveler Accommodations and Telecommunications Support sectors as the most ripe for integrating fuel cell technologies. Although the initial ranking grouped the Traveler Accommodations industry sector into the First (top) Tier, it will not be further considered in the detailed industry sector analysis. The exclusion of the Traveler Accommodations industry sector does not imply that it should not be considered as a potential market for fuel cells. The Traveler Accommodations industry sector was compared to the Education Services industry sector and determined to have similar energy needs and market potential with respect to fuel cell compatibility. Therefore, the Educational Services industry sector was selected for further evaluation based on the greater accessability to data representing the industry sector and the enhanced resolution of the industry sector with respect to types of establishments and their respective energy demands. Specifically, the NAICS classification/category for the Traveler Accommodations industry sector includes traditional facilities that provide hotel accommodations, smaller entities such as bed and breakfasts and establishments that provide road-side services. The inclusion of these entities skewed and over represented the true number of establishments that were likely to use fuel cell technologies within this industry sector.

When excluding the non-traditional hotel accommodations the establishments/facilities included in the Traveler Accommodations and Education Services industry sector have building sizes/types and electric and thermal energy demands that are very similar.

The remaining sectors, Agriculture, Educational Services (Educational Facilities), Hospitals, and Telecommunications Support sectors, can utilize fuel cells as an alternative power source to the main grid with significant environmental and economic benefits. Additionally, the WWTP industry sector was included in part due to its interest to the U.S. EPA. The environmental and economic benefits for the down-selected industrial sectors are discussed in greater detail in the chapters that follow.

Agriculture-Livestock — Chapter 5.0
Educational Services — Chapter 6.0
Hospitals — Chapter 7.0
Telecommunications Support — Chapter 8.0
Wastewater Treatment Plants — Chapter 9.0

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# 5.0 Agriculture-Livestock Industry Sector Analysis

Ranked within the top tier as a result of the industry prioritization step in Chapter 4.0, the Agriculture-Livestock industry sector was identified as one of five sectors having the greatest fuel cell market potential. In the year 2010, an estimated 192,616 agriculture-livestock establishments will have an average power demand compatible with anticipated fuel cell technologies. This market potential represents 18% of total number of agriculture-livestock establishments.

The Agriculture-Livestock industry sector is also a promising market because of the enormous biogas energy potential of livestock animal wastes (i.e., manure). Biogas, a combustible gas derived from the decomposition of biological animal waste (i.e., biomass), is composed of methane ($CH_4$) and carbon dioxide ($CO_2$)with traces of $H_2S$, $N_2$, $H_2$, and CO. In 2010, the Agriculture-Livestock establishments are expected to generate 29,596,093 metric tons of biogas. Since biogas is a source of methane, the expectation is that it could be an inexpensive fuel source for an on-site fuel cell energy system. The key to making this biomass energy source available for fuel cells is two fold. First, the manure must be collected in sufficient quantities to justify outfitting the fuel cell to utilize this alternative energy feedstock. Collection is accomplished relatively easily at feedlots and other confined space animal feeding operations. However, it is probably not cost effective for open, range land style livestock establishments which would incur greater costs in collecting the biomass. The second requirement is that an Agriculture-Livestock establishment must have a process to convert the collected biomass into a more usable biogas form. This process can occur with several techniques. One method that has been coupled with a fuel cell is an anaerobic digester, which is an elaborate mechanism that uses microorganisms to extract the methane-containing biogas. Other simpler methods, such as extracting the biogas from manure decomposing in a lined, possibly-heated, and covered landfill-type pit, have proved less viable because of their inability to produce a steady output of biogas.

A detailed analysis of the potential fuel cell market within the Agriculture-Livestock industry sector is presented in this chapter which has been divided into the eight areas listed below:

- Definition of the Agriculture Industry Sector — Section 5.1
- Industry Sector Profile for 2010 — Section 5.2
- Fuel Cell Market Potential — Section 5.3
- Technical Assessment — Section 5.4
- Cost Assessment — Section 5.5
- Environmental Assessment — Section 5.6
- Institutional Considerations — Section 5.7
- Summary of Fuel Cell Opportunities in the Agriculture Industry Sector — Section 5.8

Each area is described in detail below.

## 5.1 Definition of Agriculture-Livestock Industry Sector

The agriculture-livestock industry sector being considered in this work comprises establishments primarily engaged in raising livestock and poultry (cattle and calves, beef cows, hogs and pigs, layers and pullets, broilers and other meat-type chickens). As defined by the NAICS, this industry includes the following sub-sectors:

- 1121 Cattle Ranching and Farming
- 112111 Beef Cattle Ranching and Farming
- 112112 Cattle Feedlots
- 11212 Dairy Cattle and Milk Production
- 1122 Hog and Pig Farming
- 1123 Poultry and Egg Production
- 11231 Chicken Egg Production
- 11232 Broilers and Other Meat Type Chicken Production
- 11233 Turkey Production
- 11234 Poultry Hatcheries
- 11239 Other Poultry Production
- 1124 Sheep and Goat Farming
- 11242 Goat Farming

## 5.2 Industry Sector Profile for 2010

The industry sector profile is based on data for 2010 because the benefits of fuel cell technology in terms of technology maturity, cost benefits and other factors affecting the ease of market penetration are more fully realized in 2010. The results of the 2010 industry sector profile for the agriculture-livestock industry were derived from the 1997 U.S. Agriculture Census data using an estimated growth rate for the industry while holding other factors constant. The data presented in this market profile are necessary to properly characterize, and communicate the greatest opportunities for implementing fuel cell technology within this industry sector. The methodology used to generate the agriculture-livestock industry sector profile for 2010 is explained below.

### 5.2.1 Methodology

In order to estimate the electrical and thermal demand of small, medium, and large agriculture-livestock establishments in the United States (U.S.), 1997 Census of Agriculture data characterizing the agriculture industry sector in terms of the number of acres per establishment were combined with detailed 1995 energy statistics (amount of energy consumed per acre). It was assumed that the amount of energy consumed per acre would remain constant between 1995 and 1998 to correlate the data to determine the average power demand, total energy consumption (relative to the U.S. electrical grid), and the pounds of air emissions released from U.S. power plants (based on 1998 E-Grid data) as a result of the amount of energy consumed by small, medium, and large farms in 1999.

The results were scaled from the present to 2010 by assuming a 0% annual growth in the agriculture-livestock industry sector. The growth rate was determined by analyzing the 1997 Census of Agriculture data for the growth rate in the number of establishments in the agriculture-livestock industry sector showing a slight decrease of 0.15% over a period of five years. Therefore, the number of establishments (small, medium, and large) was kept constant throughout 2010. In addition, the following variables were assumed to remain constant:

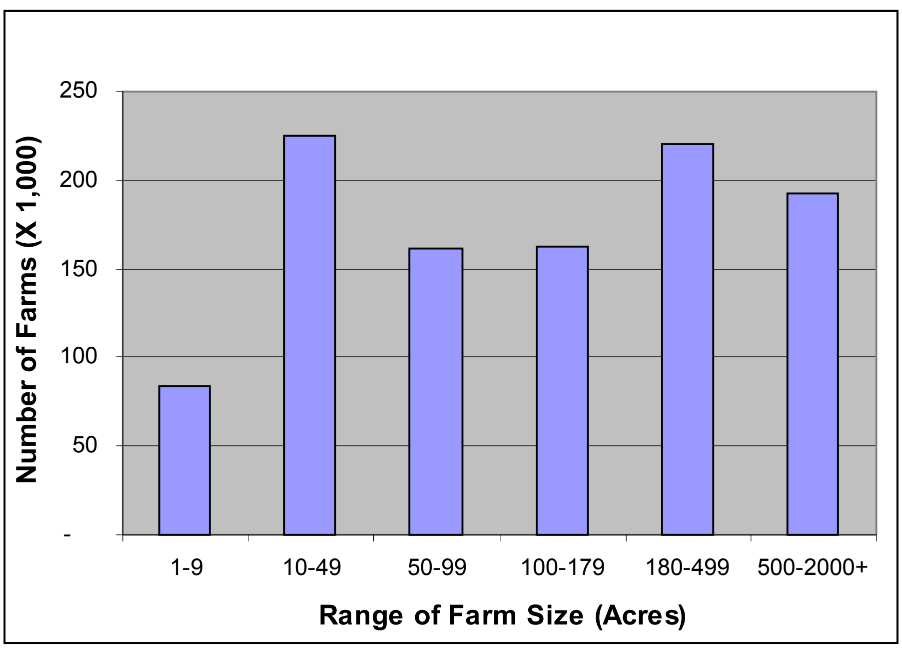
- Amount of energy consumed per Agriculture acre
- Distribution of small, medium, and large Agriculture facilities within the industry sector
- Emissions profile from the U.S. electricity grid was assumed to remain constant per kilowatt (kW) of power consumed.

### 5.2.2 Size of Industry Sector

In the past five years, the agriculture-livestock industry showed no increase in the number of facilities nationwide. For lack of contradictory data extending over a significant period of time, and considering the nature of the agriculture-livestock industry, it is reasonable to assume no growth over the next ten years in that industry.

**EXHIBIT 5-1: DISTRIBUTION OF ESTABLISHMENTS BY FARM SIZE FOR THE AGRICULTURE INDUSTRY IN 2010**

The agriculture-livestock industry sector is comprised of approximately 1,046,863 establishments that range in size from 1 to greater than 2,000 acres. For this report, the agriculture-livestock establishments were divided into the following six classes based on the



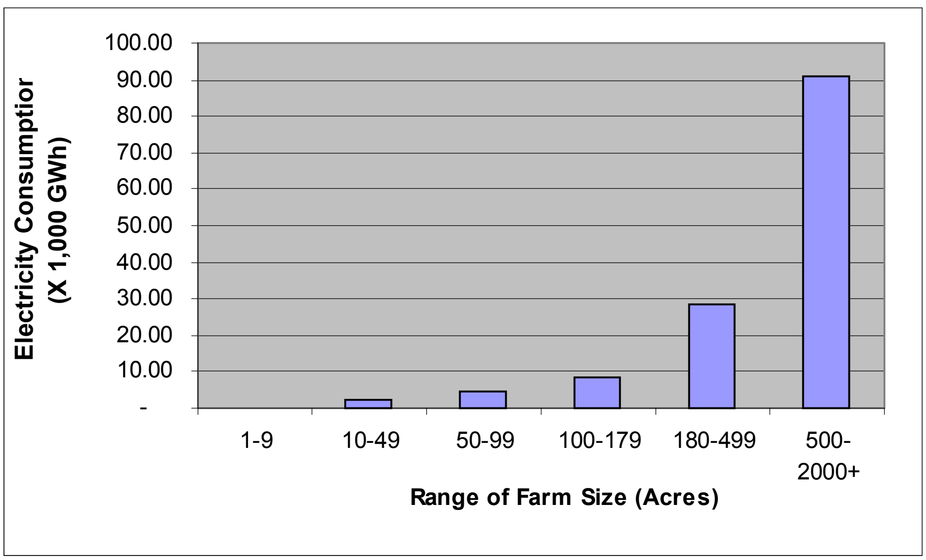
acres of land used for raising livestock; 1 to 9, 10 to 49, 50 to 99, 100 to 179, 180 to 499 and 500 to more than 2000 acres. Exhibit 5-1 presents a distribution of the agriculture-livestock establishments by size. Exhibit 5-1 indicates that approximately 53% of the establishments are between 10 and 179 acres and 40% are greater than 180 acres. Small establishments (<9 acres) account for only 7% of the total in the U.S.

### 5.2.3 Annual Energy Consumption and Related Utility Plant Air Emissions

A breakdown of the energy consumption of farms shows that for a typical farm, the consumption of electricity is about 0.38 MWh per acre, and the thermal consumption is equal to 88% the electrical consumption. The electricity needs of agriculture-livestock establishments by size is presented in Exhibit 5-2. Size is expressed in terms of the number of acres per establishment.

**EXHIBIT 5-2: DISTRIBUTION OF ELECTRICITY CONSUMPTION PER ACRE RANGE IN 2010**

The agriculture-livestock establishments that are between 1 and 499 acres consumed 44,283 GWh/year of electricity. This figure represents 33% of total electricity consumption for




the agriculture-livestock industry sector. Establishments that consume over 91,043 GWh/year of electricity (67% of total) are at least 500 acres or more.

As illustrated in Exhibit 5-2, agriculture-livestock establishments range in size and thus have a wide range of energy needs. Smaller establishments typically require less energy than larger ones. These differing energy needs will impact the use of fuel cells within the sector as an alternative to traditional power sources, especially the main power grid. A detailed analysis of electricity and heat consumption, along with the emissions produced by the power grid during electricity production for these establishments is presented in Exhibit 5-3.

The average power demand is the primary metric to which the power output of a fuel cell is compared in order to evaluate its suitability for use. It is a measure of the instantaneous power need of a given facility. It is calculated by assuming that electricity at the establishments is consumed 24 hours a day, 365 days a year or 8,760 hours per year.

**EXHIBIT 5-3: AGRICULTURE INDUSTRY ENERGY CONSUMPTION AND RELATED UTILITY PLANT AIR EMISSIONS FOR 2010**

| ESTABLISHMENT SIZE (ACRES) | 1–9 | 10–49 | 50–99 | 100–179 | 180–499 | 500–2000+ | TOTAL |
|---|---|---|---|---|---|---|---|
| Number of Establishments | 84,059 | 224,957 | 161,549 | 163,140 | 220,541 | 192,616 | 1,046,863 |
| Total Electricity Consumption (MWh) | 158,928 | 2,551,915 | 4,581,539 | 8,636,444 | 28,354,013 | 91,043,383 | 135,326,221 |
| Average Power Demand (kW) | 0.2 | 1.3 | 3.2 | 6.0 | 14.7 | 54.0 | N/A |
| Total Thermal Consumption (MWh) | 139,857 | 2,245,685 | 4,031,755 | 7,600,071 | 24,951,531 | 80,118,177 | 119,087,075 |
| Total $CO_2$ Emissions (million lbs.) | 226 | 3,625 | 6,507 | 12,267 | 40,272 | 129,312 | 192,208 |
| Total $SO_2$ Emissions (million lbs.) | 1.2 | 19 | 34 | 65 | 213 | 683 | 1,015 |
| Total $NO_x$ Emissions (million lbs.) | 0.6 | 9 | 16 | 31 | 101 | 323 | 480 |
| Total Emissions (millions lbs.) | 227 | 3,653 | 6,558 | 12,362 | 40,585 | 130,318 | 193,703 |
| Methane Emissions (metric tons) | 34,758 | 558,108 | 1,001,991 | 1,888,806 | 6,201,075 | 19,911,355 | 29,596,093 |

* N/A: Not applicable, for instance Average Power demand is specific to a single facility.
Note: Average power demand is based on an annual usage of 8,760 hours per year (100%). Power demand represents the average over a one-year period of time, therefore, it does not reflect the actual power demands of a specific establishment or industry (i.e., high demand and low demand).

Emissions generated during electricity production in the U.S. were calculated using a national average of 1420.33 lbs./MWh of $CO_2$, 7.5 lbs./MWh of $SO_2$ and 3.55 lbs./MWh of $NO_x$ as derived from EPA's E-Grid database using power plant emissions factors for the National energy grid. Over the next ten years, the National average for air emissions released from the U.S. production of electricity (electricity grid) will change due to advanced technologies for traditional energy sources and the market penetration of new and distributed generation energy sources. Modeling and prediction of potential changes to future environmental burdens from U.S. energy sources was beyond the scope of this effort; therefore, a level of uncertainty is accepted in the predicted mass of pollution created or avoided.

## 5.3 Fuel Cell Market Potential

The fuel cell market potential is determined by matching the average power demand of each agriculture-livestock establishment size class (i.e., 1 to 9, 10 to 49, 50 to 99, 100 to 179, 180 to 499, and 500 to 2,000+) from the industry sector profile (see Section 5.2.3) with the estimated compatibility range of each type of fuel cell (see Chapter 3.0 for an overview of each type of fuel cell). Exhibit 5-4 highlights the potential market size for different fuel cell technologies in 2010.

Only three fuel cell technologies (PAFC, PEMFC and SOFC) have market potential in the agriculture- livestock industry sector with respect to the projected operating ranges available in 2010 matching the energy demands of the industry. Exhibit 5-4 highlights the potential market size for different fuel cell technologies in 2010, with Y (Yes) indicating where a particular fuel cell technology is expected to be marketable and N (No) indicating where there is no potential market. In 2010 only those agriculture-livestock establishments that are 500 - 2000+ acres can utilize the fuel cell technology. Specifically, PAFC, PEMFC and SOFC have the greatest potential market size comprising 192,616 establishments representing 18% of the Agriculture market. However, MCFC technology has no market potential because of its relatively narrow operating range (power output).

**EXHIBIT 5-4: FUEL CELL MARKET POTENTIAL FOR 2010**

| FARM SIZE CLASS (ACRES | NUMBER OF ESTABLISHMENTS | AVERAGE POWER DEMAND (kW) | FUEL CELL TECHNOLOGY & PROJECTED OPERATING RANGE FOR 2010 [A] | | | |
|---|---|---|---|---|---|---|
| | | | PAFC (50 – 250 kW) | PEMFC (50 – 250 kW) | SOFC (50 kW – 5 MW) | MCFC (250 kW – 5 MW) |
| 1–9 | 84,059 | 0.2 | N | N | N | N |
| 10–49 | 224,957 | 1.3 | N | N | N | N |
| 50–99 | 161,549 | 3.2 | N | N | N | N |
| 100–179 | 163,140 | 6.0 | N | N | N | N |
| 180–499 | 220,541 | 14.7 | N | N | N | N |
| 500–2,000+ | 192,616 | 54.0 | Y | Y | Y | N |
| Potential Market Size: | | | 192,616 | 192,616 | 192,616 | 0 |

[A] In determining fuel cell size compatibility, the projected operating capabilities for 2010 were expanded by reducing the lower range by 50% and increasing the upper range by 500% to account for the ability to operate the fuel cell at 50% capacity or operate 5 fuel cell systems in parallel.

## 5.4 Technical Assessment

The technical feasibility of fuel cells entering the agriculture-livestock industry sector has been organized into the technical factors presented below. These factors were identified earlier in Chapter 3.0.

- Technology Maturity
- Physical Space Requirements
- Infrastructure Requirements
- Start-up time
- Co-generation Potential
- Fuel Efficiency
- Output Reliability/Consistency
- Fuel Flexibility

Each technical factor is described below with respect to the Agriculture industry sector. The relative importance of each factor to the Agriculture industry sector is denoted by the number of " i " to right of the heading. One star (minimum) indicates low importance and three stars (maximum) indicates high importance.

### 5.4.1 Technology Maturity i i i

Most agriculture-livestock establishments perceive power generation to be outside the sphere of their current mission. The maturity of the technology is expected to be a significant factor affecting fuel cell technology acceptance by this industry.

### 5.4.2 Physical Space Requirements i

This is not a difficult problem to solve as most agriculture-livestock establishments operate in open spaces.

### 5.4.3 Infrastructure Requirements i i

Acceptance of fuel cell technology and related costs by agriculture-livestock establishments is likely to be dependent upon the additional costs associated with the transport and storage of natural gas, methane or hydrogen. The needed infrastructure for this delivery is likely to be a relatively significant factor in the acceptance of the technology.

### 5.4.4 Start-up Time i

It is likely that fuel cells installed at agriculture-livestock establishments would have to operate continuously in order to minimize the capital cost per unit of power generated. Continuous operation would make start-up time relatively insignificant in the acceptance of the technology.

### 5.4.5 Co-generation Potential i i i

Agriculture-livestock establishments need an external source of heat for climate control inside of facilities (e.g., barns and chicken coops). The ability of fuel cells to use the heat generated in their operation to return heat to the establishment can be appreciable in that it will eliminate the need for an alternative source of heat. The potential for co-generation is a crucial factor in the acceptance of the technology.

### 5.4.6 Fuel Efficiency i i

Since agriculture-livestock establishments generate a fuel source onsite (biogas), fuel efficiency is an important factor in the acceptance of the technology at agriculture-livestock establishments.

### 5.4.7 Output Reliability/Consistency i

The reliability of the fuel cell units will not be a critical factor in determining the cost of the power generated and in determining the viability of fuel cell technology in agricultural establishments. No sensitive equipment is used at agriculture-livestock establishments, which allows these facilities to sustain power variations. Thus, output reliability/consistency is not considered an important factor in the acceptance of the technology.

### 5.4.8 Fuel Flexibility i i

Since the agriculture-livestock establishments generate a fuel source onsite (biogas), fuel flexibility is an important factor with regard to acceptance of the technology in this industry sector.

## 5.5 Cost Assessment

The purpose of the cost assessment is to determine the financial viability of fuel cells being accepted within the agriculture-livestock industry sector. In general, fuel cells will be accepted if the cost of operating and maintaining a fuel cell is equal to or less than the cost associated with purchasing energy from a local supplier; *if*, the fuel cell system can improve the reliability (power quality) of electricity for these establishments.

The cost assessment is divided into two parts: 1) the estimated cost savings of purchasing and operating a fuel cell in the agriculture-livestock industry sector in the year 2010; and 2) a qualitative assessment of the relative importance of various economic factors to the agriculture-livestock industry sector.

### 5.5.1 Estimated Cost Savings

Information was collected from fuel cell manufacturers to estimate the cost of electricity produced by fuel cells. The cost of electricity includes the installed cost (over a 10 year service life), the fuel purchase cost, and the operation and maintenance costs (O&M). Exhibit 5-5 summarizes the cost of fuel cells for the year 2001 and Exhibit 5-6 summarizes the fuel cell cost predictions for the year 2010. Unlike previous sections in this chapter, fuel cell and/or industry market data representing the year 2001 is presented in conjunction with 2010 predictions due to the significant level of uncertainty in the 2010 cost estimates. The increased level of uncertainty in the cost predictions are based on the lack of maturity and history of fuel cells. The consumption of fuel is estimated at 1,900 $ft^3$/hour of methane; as reported by the Energy Research and Development Center (US Army Corps of Engineers) during the EPA Fuel Cell Workshop held in Cincinnati Ohio, June 26–27 2001.

The total cost, as expressed in the rightmost column of both Exhibit 5-5 and Exhibit 5-6, is the sum of the installation cost over 10 years, the operation and maintenance (O&M) cost and the fuel cost.

**EXHIBIT 5-5: ESTIMATES OF OVERALL ANNUAL FUEL CELL COSTS (2001)**

| | AVERAGE INSTALLED COST ($/kW) | AVERAGE INSTALLED COST (¢/kWh) | INSTALLATION COST OVER 10 YEARS (¢/kWh) | O&M COST (¢/kWh) | FUEL COST (¢/kWh) | TOTAL COST (¢/kWh) |
|---|---|---|---|---|---|---|
| PAFC | 2,500 | 28.54 | 2.85 | 1.75 | 5.08 | 9.68 |
| PEMFC | 10,000 | 114.16 | 11.42 | 1.75 | 5.08 | 18.25 |
| SOFC | 10,000 | 114.16 | 11.42 | 1.5 | 5.08 | 18.00 |
| MCFC | 8,000 | 91.32 | 9.13 | 1.5 | 5.08 | 15.71 |

Note: Total cost is the sum of the installed cost over 10 years, O&M costs and fuel costs. Source for fuel costs is AEO 2001 projections for 2010.

The cost projections for 2010 provided by manufacturers indicate a sharp decline in installed costs, O&M costs, and fuel costs for each fuel cell technology. The combination of all these declines results in an overall decrease in total costs for all fuel cells between 2001 and 2010 of approximately 55 % in average per fuel cell.

**EXHIBIT 5-6: ESTIMATES OF OVERALL ANNUAL FUEL CELL COSTS (2010)**

| | AVERAGE INSTALLED COST ($/kW) | AVERAGE INSTALLED COST (¢/kWh) | INSTALLATION COST OVER 10 YEARS (¢/kWh) | O&M COST (¢/kWh) | FUEL COST (¢/kWh) | TOTAL COST (¢/kWh) |
|---|---|---|---|---|---|---|
| PAFC | 875 | 9.99 | 1.00 | 1.00 | 4.16 | 6.16 |
| PEMFC | 1,200 | 13.70 | 1.37 | 1.00 | 4.16 | 6.53 |
| SOFC | 1,250 | 14.27 | 1.43 | 1.00 | 4.16 | 6.59 |
| MCFC | 1,250 | 14.27 | 1.43 | 1.00 | 4.16 | 6.59 |

Note: Total cost is the sum of the installed cost over 10 years, O&M costs and fuel costs.

The estimated costs saved by utilizing fuel cell technology is derived by subtracting fuel cell costs from electricity prices when provided by a local electricity supplier. The average annual electricity cost, for the agriculture-livestock industry, is 7.0 ¢/kW. Exhibit 5-7 presents for the agriculture-livestock industry the cost savings associated with utilizing each type of fuel cell technology in 2001 and Exhibit 5-8 presents the cost savings estimated for 2010. Cost savings are only provided for employment size classes that have a market potential for utilizing fuel cells (see Section 5.3, Fuel Cell Market Potential). Cost savings presented in parentheses indicate negative savings which means that the current fuel cell electricity cost exceeds the average annual electricity cost incurred within the agriculture-livestock industry sector from local electricity suppliers.

**EXHIBIT 5-7: FINANCIAL SAVINGS FROM FUEL CELL IMPLEMENTATION IN THE AGRICULTURE INDUSTRY (2001)**

| FARM SIZE CLASS (ACRES) | NUMBER OF ESTABLISHMENTS | COST OF ELECTRICITY (¢/kWh) | PAFC (¢/kWh) | PEMFC (¢/kWh) | SOFC (¢/kWh) | MCFC (¢/kWh) |
|---|---|---|---|---|---|---|
| 500–2,000+ | 192,616 | 7.0 | N/A | N/A | (11.0) | N/A |

A direct implementation of fuel cells in the agriculture-livestock industry sector in 2001 is not economically profitable. Projections provided from manufacturers, as well as energy projections provided by the Energy Information Administration (EIA), provide a more positive economic outlook for implementing fuel cells in the agriculture-livestock industry sector for the year 2010.

**EXHIBIT 5-8: FINANCIAL SAVINGS FROM FUEL CELL IMPLEMENTATION IN THE AGRICULTURE INDUSTRY (2010)**

| FARM SIZE CLASS (ACRES) | NUMBER OF ESTABLISHMENTS | COST OF ELECTRICITY (¢/kWh) | PAFC (¢/kWh) | PEMFC (¢/kWh) | SOFC (¢/kWh) | MCFC (¢/kWh) |
|---|---|---|---|---|---|---|
| 500–2,000+ | 192,616 | 7.0 | 0.8 | 0.5 | 0.4 | N/A |

PAFC, PEMFC and SOFC technologies are economically feasible choices for the agriculture-livestock industry with a cost savings in 2010 of up to 0.8 ¢/kWh for PAFC's. This would be equivalent to an annual savings of $3,780/year for an agriculture-livestock establishment with more than 500 acres. Extrapolating the cost savings for a PAFC for the estimated market potential of 192,616 establishments within the agriculture-livestock industry sector, the potential annual savings for the agriculture-livestock industry in 2010 would be $728 million/year.

### 5.5.2 Economic Factors on Market Penetration

The economic feasibility of fuel cells entering the agriculture-livestock industry sector has been organized into the economic factors presented below. These factors were identified earlier in Chapter 3.0.

- Acquisition Costs
- Annual O&M Costs
- Other Indirect Costs
- Lead Time
- Service Life
- Annual Revenue from the Sale of Electricity
- Possible Energy Tax Credits/ Rebates/Grants
- Emissions Credits

Each economic factor is described below with respect to the agriculture-livestock industry sector. The relative importance of each factor to the agriculture-livestock industry sector is denoted by the number of " ¡ " to right of the heading. One star (minimum) indicates low importance and three stars (maximum) indicates high importance.

#### 5.5.2.1 Acquisition Costs ¡ ¡ ¡

For fuel cells to be used in agriculture-livestock establishments, the unit cost of power they produce must be comparable or less than the cost of power available through other means (i.e., purchased grid power). As a component of the unit cost per kWh produced, acquisition costs will be an important factor in the acceptance of the technology.

#### 5.5.2.2 Annual Operation and Maintenance (O&M) Costs ¡ ¡ ¡

As a component of the unit cost per kWh produced, annual O&M costs will be an important factor in the acceptance of the technology in agriculture-livestock establishments.

#### 5.5.2.3 Other Indirect Costs ¡ ¡ ¡

As a component of the unit cost per kWh produced, other indirect costs of fuel cells will be an important factor in the acceptance of the technology.

#### 5.5.2.4 Lead Time ¡

Use of fuel cell technology would be a long term capital improvement that would be permanent in nature. Thus, long lead times would not be a significant factor in the acceptance of the technology.

#### 5.5.2.5 Service Life ¡

The Agricultural industry generally expects equipment to have a useful service life of 10 years. Thus, fuel cells are expected to have a service life similar to other agriculture-livestock activities. Service life is not expected to be a significant factor in the acceptance of the technology.

#### 5.5.2.6 Annual Revenue from the Sale of Electricity ¡

Electricity produced by fuel cells at agriculture-livestock establishments would be consumed onsite. Thus, revenue for the sale of electricity, while possibly an important consideration for a few facilities, will probably not be an important factor for the industry as a whole.

#### 5.5.2.7 Possible Energy Tax Credits/Rebates/Grants ¡ ¡

Because the decision to employ fuel cell technology at agriculture-livestock establishments will be primarily economically driven, tax credits/rebates/grants could be an important stimulus to developing the acceptance of the technology.

#### 5.5.2.8 Emissions Credits i

Since a program for emissions credits for employing fuel cell technology do not currently exist, this is not an important factor in the acceptance of the technology.

## 5.6 Environmental Assessment

The purpose of the environmental assessment is to determine the potential reduction in air emissions ($CO_2$, $SO_2$ and $NO_x$) and the conservation of natural resources associated with utilizing fuel cells as the primary energy source in the agriculture-livestock industry sector as opposed to energy from traditional U.S. energy plants. A qualitative assessment of the environmental factors that influence the marketability of fuel cells is also included as part of the environmental assessment. In general, fuel cells have a large environmental advantage over traditional sources of energy (as represented by the national average for the U.S. energy grid). However, a detailed life-cycle assessment would be necessary to determine the actual environmental benefits of competing fuel cell technologies to the current U.S. energy grid.

The results of the environmental assessment are divided into three parts: 1) pollution avoided ($CO_2$, $NO_x$, $SO_2$); 2) natural resources conserved; and 3) the environmental factors on market penetrations. Each section is described below.

### 5.6.1 Pollution Avoided ($CO_2$, $SO_2$, NOx)

The avoided pollution is determined by subtracting the pollution emitted by fuel cells if they were used as a power source instead of the power grid from the pollution emitted by the power grid based on the electricity consumption of the agriculture-livestock industry sector. The calculation is as follows:

Pollution Avoided = (Pollution Emitted by the Grid) – (Pollution Emitted by Fuel Cells)

The utilization of fuel cells in general reduces emissions as illustrated by the performance specifications of the different types of fuel cells. Fuel cells produce low levels of emissions per kWh of electricity compared to the emissions produced by the power grid per kWh of electricity. The “pollution avoided,” as mentioned above, is calculated to determine the environmental advantages of fuel cells as an alternative primary source of power. Exhibit 5-9 illustrates the potential magnitude of pollution avoided if fuel cells were fully implemented (100% of the market potential) within the agriculture-livestock industry sector in the years 2001 and 2010.

The percentage of pollution avoided when using fuel cells instead of the main grid is also provided for 2001 and 2010 in Exhibit 5-9.

**EXHIBIT 5-9: POTENTIAL POLLUTION AVOIDED IF FUEL CELLS OBTAINED 100% OF THE MARKET POTENTIAL IN THE AGRICULTURE INDUSTRY SECTOR IN 2001 AND 2010**

| Farm Size Class (Acres) | 2001 | | 2010 | |
|---|---|---|---|---|
| | POLLUTION AVOIDED (MILLION lbs.) | PERCENT REDUCTION (%) | POLLUTION AVOIDED (MILLION lbs.) | PERCENT REDUCTION (%) |
| 500–2000+ | 36,985 | 28 | 36,978 | 28 |

Based on the findings in Exhibit 5-9, the environmental advantages of producing energy using fuel cells is a 28% reduction in air emissions. A comprehensive analysis of competing fuel cell technologies to traditional energy sources (U.S. energy grid) would be necessary to improve the accuracy of the rough-order-of-magnitude assessment conducted.

### 5.6.2 Calculate Fuel Conserved by Using Fuel Cells in 2001 and 2010

In addition to reducing air emissions, the use of fuel cells reduces the amount of fossil fuels used to generate electricity. Of the total electricity consumed in the U.S. in 1999, coal generated 51%, oil generated 3.2%, natural gas generated 15.3%, nuclear generated 19.7%, hydroelectric sources generated 8.3%, and other sources generated 2.4% (EIA). The proportions are very similar for 1998, and it is reasonable to assume that the same proportions apply to the year 2001. It is possible to calculate the quantities of coal, oil and natural gas that would not be consumed if fuel cells were to be used instead as a primary source of power. Exhibits 5-10 and 5-11 illustrate the potential magnitude of "displaced fuel," or natural resources conserved if fuel cells were fully implemented (almost 100% of the market potential) within the agriculture-livestock industry sector in the years 2001 and 2010.

**EXHIBIT 5-10: NATURAL RESOURCES CONSERVED IN 2001**

| FARM SIZE CLASS (ACRES) | NUMBER OF ESTABLISHMENTS | ELECTRICITY CONSUMPTION (MWh/yr) | NATURAL RESOURCES CONSERVED | |
|---|---|---|---|---|
| | | | COAL (MILLION lbs.) | OIL (THOUSAND gal.) |
| 500–2,000+ | 192,616 | 91,043,383 | 41,466 | 285,962 |

**EXHIBIT 5-11: NATURAL RESOURCES CONSERVED IN 2010**

| FARM SIZE CLASS (ACRES) | NUMBER OF ESTABLISHMENTS | ELECTRICITY CONSUMPTION (MWh/yr) | NATURAL RESOURCES CONSERVED | |
|---|---|---|---|---|
| | | | COAL (MILLION lbs.) | OIL (THOUSAND gal.) |
| 500–2,000+ | 192,616 | 91,043,383 | 40,145 | 285,962 |

Exhibit 5-12 shows the amount of natural gas consumed when fuel cells are implemented in the Agriculture industry, the amount of natural gas displaced by not using current energy sources, and the resulting net increase in natural gas consumption.

**EXHIBIT 5-12: ACTUAL FUEL CONSUMED AND CONSERVED WHEN USING FUEL CELLS IN 2010**

| FARM SIZE CLASS (ACRES) | AVERAGE POWER DEMAND (kW) | NATURAL GAS CONSUMED (MILLION cu. ft.) | NATURAL GAS DISPLACED (MILLION cu. ft.) | NET NATURAL GAS (MILLION cu. ft.) |
|---|---|---|---|---|
| 500–2,000+ | 54 | 865,594 | 82,389 | (783,205) |

### 5.6.3 Environmental Factors for Market Penetration

The key environmental factors associated with fuel cells entering the agriculture industry sector has been organized into the environmental factors presented below. These factors were identified earlier in Chapter 3.0.

- Air Emissions
- Wastewater Production
- Solid Waste Production
- Resource Usage
- Life-Cycle Related Benefits

Each environmental factor is qualitatively described below with respect to the Agriculture industry sector. The relative importance of each factor to the agriculture industry sector is denoted by the number of " i " to right of the heading. One star (minimum) indicates low importance and three stars (maximum) indicates high importance.

#### 5.6.3.1 Air Emissions i i

Air emissions due to agriculture-livestock establishments come not only from the emissions produced by the power grid during electricity production, but also from livestock.

Since using fuel cell technology can show a positive reduction in associated air emissions, this is an important factor in evaluating potential fuel cell use.

#### 5.6.3.2 Wastewater Production i

No significant quantities of wastewater emissions are expected to be generated by fuel cells. Thus wastewater generation is not expected to be an important factor in the acceptance of the technology.

#### 5.6.3.3 Solid Waste Production i

Solid waste generation from fuel cells generally consists of non-hazardous materials (i.e., filter cartridges) and spent catalysts which can be reclaimed and recycled. Solid waste generation for fuel cells is expected to be similar and is comparable on a per unit basis to the waste generated by the power grid. Thus, solid waste generation is not expected to be an important factor with regard to acceptance of the technology in agriculture-livestock establishments.

#### 5.6.3.4 Resource Usage i i

The principal resource required is a gas hydrocarbon fuel as a feedstock for the fuel cells. Even though biogas will be generated onsite (from manure), feedstock will also have to be purchased. Thus, because of the added costs associated with purchase of feedstock, resource usage is anticipated to be a relatively important factor with regard to acceptance of the technology in agriculture-livestock establishments.

#### 5.6.3.5 Life-Cycle Related Benefits i i

Fuel cell technology is considered to be almost pollution free during its operation (minimal $CO_2$, $SO_2$ and $NO_x$, cooling/rinse water, and negligible solid waste). In terms of downstream end-of-life impacts, most manufacturers are reporting that they expect the majority of the fuel cell components to be recyclable (95% by weight according to IFC). Most of the remaining 5% are anticipated to be landfilled with less than 1% being hazardous waste (heavy metal wastes from the cell and/or ancillary fluids). Since very few fuel cell systems have been decommissioned to date, these end-of-life estimates need to be revised as substantiating data become available. In terms of upstream impacts, the life cycle impacts are anticipated to be those common to manufacturing/assembly activities (e.g., structural frame, plumbing, and insulation) including solvents and chemicals from metal processing, paints and coatings, and associated other assembly/production by-products. Thus, compared to electricity produced by the power grid, life-cycle related benefits are anticipated to be relatively important factors in the acceptance of the technology in the agriculture-livestock industry.

## 5.7 Institutional Considerations

Institutional considerations affecting the marketability of fuel cells in the agriculture-livestock industry sector have been organized into the factors presented below. These factors were identified earlier in Chapter 3.0.

- Regulatory Barriers
- Market/Customer Acceptance
- Staff Experience/Training Required

Each institutional factor is described below with respect to the agriculture-livestock industry sector. The relative importance of each factor to the agriculture-livestock industry sector is denoted by the number of " i " to right of the heading. One star (minimum) indicates low importance and three stars (maximum) indicates high importance.

### 5.7.1 Regulatory Barriers i

Because fuel cells are an emerging technology, regulatory standards and codes have not yet been developed. As fuel cells gain greater acceptance in this, and other industries, appropriate codes and standards will likely emerge. Thus, regulatory barriers are not anticipated to be an important factor in the acceptance of the technology in agricultural-livestock establishments.

### 5.7.2 Market/Customer Acceptance i i

The market/customer acceptance relates to how receptive and motivated a customer is to use a fuel cell system in place of its current sources of power. This

**Exhibit 5-13: Summary of Factors Influencing Marketability of Fuel Cells in the Agriculture-Livestock Industry Sector**

| Technical Factors | |
|---|---|
| Technology maturity | i i i |
| Physical space requirements | i |
| Infrastructure requirements | i i |
| Start-up time | i |
| Co-generation options | i i i |
| Fuel efficiency | i |
| Output reliability/consistency | i i i |
| Fuel flexibility | i i |
| **Economic Factors** | |
| Acquisition costs (purchase and installation) | i i i |
| Annual operation and maintenance costs | i i i |
| Lead Time | i |
| Other annual indirect costs (e.g., liability, environmental) | i i i |
| Service life | i |
| Annual revenue from sale of output | i |
| Annual business energy tax credits/rebates (Federal, State, local) | i i |
| Emissions credits | i |
| **Environmental Factors** | |
| Air emissions | i i |
| Wastewater releases | i |
| Solid waste (non-hazardous and hazardous) | i |
| Resource usage (water, fuel feedstock) | i i |
| Life-Cycle related benefits | i i |
| **Institutional Factors** | |
| Regulatory barriers | i |
| Management/customer acceptance | i i |
| Staff expertise/training required | i i i |

i i i — 3 Stars denote factors critical to marketability in the Agriculture-Livestock sector.

particular factor includes reviewing what the customer has invested in providing and maintaining the current power sources (which is linked to the economic factors), the willingness of a customer to utilize cutting-edge innovative technology, and for this particular sector, how the public will value and balance other benefit factors (such as the environmental) in deciding whether to use fuel cell technology.

### 5.7.3 Staff Experience/Training Required ¡ ¡ ¡

While the fuel cells themselves may be relatively simple to operate, the gas conditioning processes needed for both PAFC and PEMFC technologies may require O&M skills that may not be found in agriculture-livestock establishments. Thus, staff expertise and the training needed will be a significant factor in the acceptance of fuel cell technology in farms.

## 5.8 Summary of Fuel Cell Opportunities in the Agriculture Industry Sector

Fuel cells are one of several distributed generation technologies that will play a key role in meeting the country's increasing energy demands. The emergence of fuel cell technology in the agriculture-livestock industry as an alternative to the electric power grid is growing in acceptance because of the promising environmental and economic benefits offered in the present but particularly in the future. Fuel cells are an environmentally-friendly energy source and wide-scale adoption will have a significant effect in reducing the releases of greenhouse gases while preserving natural resources (i.e., coal, oil, natural gas, etc.).

Although quite promising, unfortunately, the current costs of fuel cell technology is very high which has prevented its penetration of the market. The relative importance of cost and other factors (e.g., technical, environmental and acceptance factors) that will influence the marketability of fuel cells in the agriculture-livestock industry sector is presented in Exhibit 5-13. The relative importance of each factor to the agriculture-livestock industry sector is denoted by the number of " ¡ " to right of the heading. One star (minimum) indicates low importance and three stars (maximum) indicates high importance.

The results of this study indicate that in 2010, the PAFC, PEMFC, and SOFC technologies can be utilized within the agriculture-livestock industry sector comprising a potential market size of 192,616 agriculture-livestock establishments (18% of the market). Those establishments with the largest acreage of land e.g. between 500 and 2,000 + are most likely to benefit from the fuel cell technology.

The maturity of the fuel cell technology is expected to be a significant factor affecting fuel cell technology acceptance by this industry.

Agriculture-livestock establishments need an external source of heat for climate control inside of barns and chicken coops. The ability of fuel cells to use the heat generated in their operation to return heat to the establishment can be appreciable in that it will eliminate the need for an alternative source of heat. The potential for co-generation is a crucial factor with regard to acceptance of the technology in these establishments. Because equipment at agriculture-livestock establishments can sustain power variations. The reliability of the fuel cell units will not be a critical factor in determining the viability of the technology. Also, since these establishments generate biogas, fuel cell flexibility holds a high priority in determining its viability in this sector.

The acceptance of fuel cell technology and related costs is likely to be dependent upon the additional costs associated with the purchase of anaerobic digester equipment to facilitate the use of biogas generated from the livestock. Additional costs related to transport and storage of natural gas, methane or hydrogen are additional factors that may affect the complete implementation of the technology. The needed infrastructure for this delivery is likely to be a relatively significant factor in the acceptance of the technology in agriculture-livestock establishments.

If fuel cells are to be used at agriculture-livestock establishments, the unit cost of power available through the electrical grid must be comparable or less than the cost of the fuel cell technology. As a component of the unit cost per kWh produced, acquisition costs, annual O& M costs and other indirect costs will be an important factor with regard to acceptance of the technology in agricultural facilities. In terms of financial savings, utilizing manufacturers' projections for 2010, a sharp decline in installed costs, O&M costs, and fuel costs for each fuel cell technology results in an overall decrease in fuel cell costs from 2001 of 55% per average fuel cell. In 2010 an estimated financial savings of $728 million is expected if fuel cell technologies are implemented in the agriculture-livestock industry.

The environmental benefits of fuel cell technology include a reduction in the generation of associated air emissions ($CO_2$, $SO_2$ and $NO_x$). In 2010, farms utilizing fuel cell technologies are expected to avoid the generation of 36,985 million lbs./year of energy-related emissions. This represents a percent reduction of 28 percent. In addition, the data collected for this study indicate that the conservation of natural resources resulting from the use of fuel cells far outweighs the associated cost of purchasing fuel for use in the fuel cell. For example, in the agriculture-livestock industry, the use of fuel cells in 2010 will result in the conservation of 24,983 million lbs. of coal and 9 million gallons of oil.

Another concern regarding the acceptance of fuel cells in the agriculture-livestock industry is staff expertise and training needed to ensure the efficient operation of the fuel cell. While the fuel cells are relatively simple to operate, the gas conditioning processes needed for both PAFC and PEMFC technologies may require O&M skills that may or may not be found at agriculture-livestock establishments. Consequently, there may be some costs associated with hiring and training staff to operate the PAFC, PEMFC and SOFC technologies.

However, despite of the various technical, economic and environmental factors discussed, the fuel cell technologies identified in this report may offer the source of power to support the energy needs of the industry sector while offering significant environmental benefits.

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# 6.0 Educational Services Industry Sector Analysis

As a result of the industry prioritization presented in Chapter 4.0, the Educational Services industry sector ranked in the First tier, identifying it as a sector having the greatest market potential for fuel cell technology. In 2010, approximately 49,282 establishments (based on the fuel cell compatibility of their average power demand) or 53% of this sector can potentially utilize fuel cell technology. It should be noted that the 5–9 employee range was included because the average power demand of that range (21.3 kW) is sufficiently close to 50% of the lowest range of fuel cell power.

This chapter provides a detailed analysis of the potential market for fuel cells within the Educational Services industry sector. The results of the detailed analysis have been divided into the following eight areas:



Each area is described in detail below.

## 6.1 Definition of Educational Services Industry Sector

The Educational services industry sector being considered in this work comprises establishments engaged in many forms of education. As defined by the NAICS (NAICS Code 611, SIC Code 8200), this industry includes the following sub-sectors. The codes presented are all NAICS, even though part of the data was researched under the SIC code.

- 6111 Elementary & secondary schools
- 6112 Junior colleges
- 6113 Colleges, universities and professional schools
- 6114 Business schools & computer & management training
- 6115 Technical and trade schools
- 6116 Other schools & instruction

## 6.2 Industry Sector Profile for 2010

The results of the year 2010 industry sector profile of the educational services industry were estimated by taking the U.S. Census Bureaus's County Business Patterns (CBP) data during the years 1993 to 1998 and using an estimated growth rate for the industry while holding other factors constant. An improved understanding of the specific energy demands of the industry as a whole is essential to identifying how this sector can benefit from fuel cell technology. The methodology used to generate the educational services industry sector profile for 2010 is explained below.

### 6.2.1 Methodology

Publicly available data characterizing the educational services industry sector (number of employees per establishment) between 1993 and 1999 was combined with detailed energy statistics (amount of energy consumed per employee, EIA) in 1995 to estimate the electrical and thermal demand of small, medium, and large educational services facilities in the United States (U.S.). The amount of energy consumed per employee in educational services was assumed to remain constant between 1995 and 1999 in order to correlate the data and determine the average power demand, total energy consumption (relative to the U.S. electrical grid), and the pounds of air emissions released from U.S. power plants (based on 1998 E-Grid data) as a result of the amount of energy consumed by small, medium, and large educational facilities in 2001.

The results were scaled from the present to 2010 by assuming an annual growth in the educational services industry sector which is the average of the annual growth in this sector between 1993 and 1999. The growth rate was determined by analyzing the CBP data for the growth rate in the number of establishments in the educational services industry sector for the past five years which showed an increase of 3.4% over that period. The number of establishments (small, medium, and large) were then scaled annually by that percentage throughout 2010. In addition, the following variables were assumed to remain constant:

- Amount of energy consumed per educational services employee
- Distribution of small, medium, and large educational services facilities within the industry sector
- Emissions profile from the U.S. electricity grid was assumed to remain constant per kilowatt (kW) of power consumed.

### 6.2.2 Size of Industry Sector

The geographic distribution of educational services facilities shows a concentration of these facilities in California, New York and Texas and along the east coast. Matching the concentration of these facilities and the distribution of electricity costs throughout the U.S. will allow for a more targeted analysis of fuel cell opportunities. Exhibit 6-1 shows the distribution of educational services facilities across the U.S.

**EXHIBIT 6-1: GEOGRAPHICAL DISTRIBUTION OF ESTABLISHMENTS FOR THE EDUCATIONAL SERVICES INDUSTRY IN 2010**

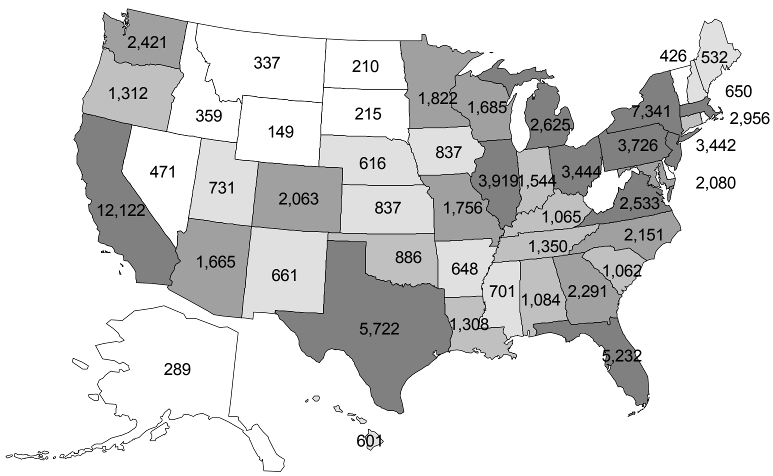



Exhibit 6-2 presents a list of the ten states with the highest number of educational services facilities.

**EXHIBIT 6-2: NUMBER OF EDUCATIONAL SERVICES ESTABLISHMENTS FOR THE TOP TEN STATES IN 2010**

| STATE | NUMBER OF ESTABLISHMENTS[A] | PERCENT (%) OF TOTAL ESTABLISHMENTS[B] |
|---|---|---|
| California | 12,122 | 13.0 |
| New-York | 7,341 | 7.9 |
| Texas | 5,722 | 6.2 |
| Florida | 5,232 | 5.6 |
| Illinois | 3,919 | 4.2 |
| Pennsylvania | 3,726 | 4.0 |
| Ohio | 3,444 | 3.7 |
| New Jersey | 3,442 | 3.7 |
| Massachusetts | 2,956 | 3.2 |
| Michigan | 2,625 | 2.8 |

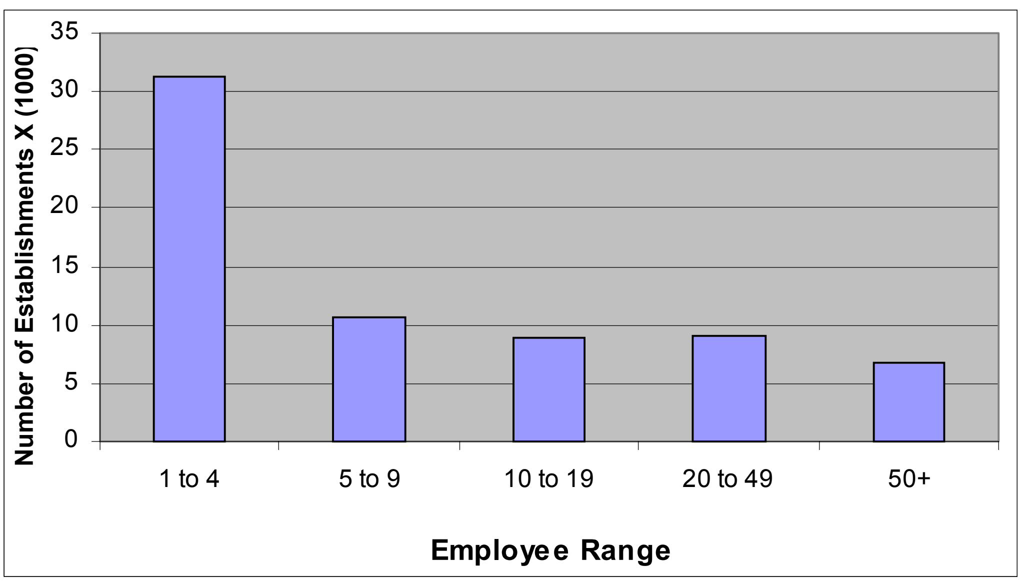
**EXHIBIT 6-2: NUMBER OF EDUCATIONAL SERVICES ESTABLISHMENTS FOR THE TOP TEN STATES IN 2010**

| STATE | NUMBER OF ESTABLISHMENTS[A] | PERCENT (%) OF TOTAL ESTABLISHMENTS[B] |
|---|---|---|
| *Subtotal* [C] | 50,529 | 54.4 |
| Other [D] | 42,360 | 45.6 |
| *Total* [E] | 92,889 | 100 |

[A] Represents the number of educational services facilities in each state.
[B] Equals the number of facilities in a state divided by the Total and then multiplied by 100.
[C] Equals the sum of facilities in the 10 states with the highest number of facilities.
[D] Equals the sum of facilities in the remaining 40 states.
[E] Equals the sum of facilities in the entire United States.

Based on the CBP data gathered between 1993 and 1999, it appears reasonable to assume a 3.4% growth over the next ten years in that industry. Exhibit 6-3 shows a distribution of the sizes of the educational services facilities in the U.S. The size of the facility is represented by the range of employees.

**EXHIBIT 6-3: DISTRIBUTION OF ESTABLISHMENTS BY SCHOOL SIZE FOR THE EDUCATIONAL SERVICES INDUSTRY IN 2010**



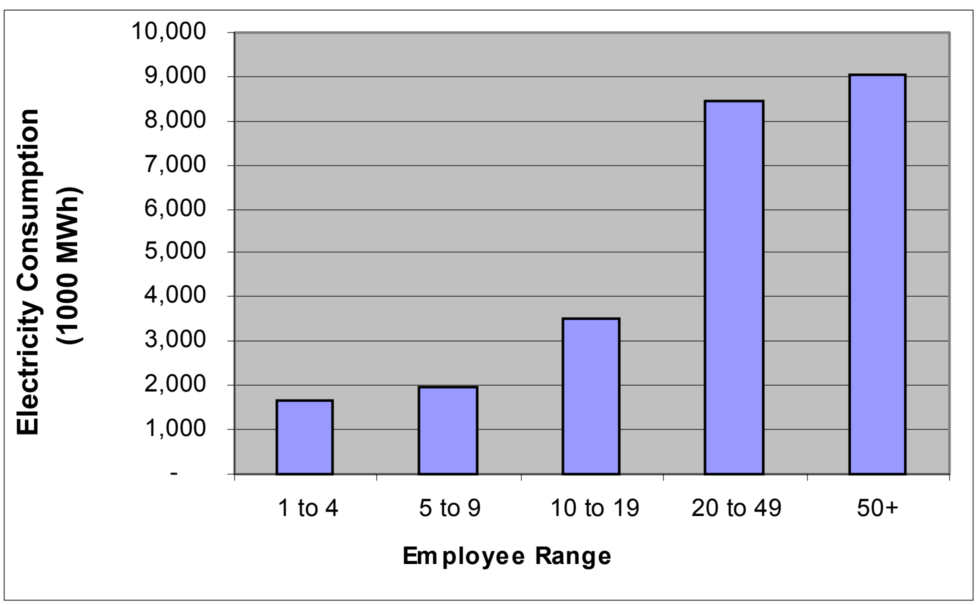
Establishments within the educational services industry sector can roughly be divided into five classes: 1 to 4, 5 to 9, 10 to 19, 20 to 49 and more than 50 employees respectively. Exhibit 6-3 illustrates the distribution of establishments relative to employee size. Within the educational services industry sector; approximately 47% of establishments employ 1 to 4 employees and only 10% of schools, such as colleges and universities, employ more than 50 employees. The remainder (43%) employ between 5 and 49 staff.

### 6.2.3 Annual Energy Consumption and Related Utility Plant Air Emissions

Energy usage in the educational services industry is derived primarily from the EIA Commercial Buildings Energy Consumption Survey (CBECS). A breakdown of the energy consumption of schools shows that for a typical school, the consumption of electricity is about 27 MWh per employee, and the thermal consumption is equal to 178 % of the electrical consumption.

Exhibit 6-4 illustrates the electricity needs by facility size. Size is expressed in terms of the number of employees per school.

**EXHIBIT 6-4: DISTRIBUTION OF ELECTRICITY CONSUMPTION PER EMPLOYEE RANGE IN 2010**



The educational facilities that have between 1 and 19 employees consume slightly over 10,000 GWh/year of electricity (29% of total electricity consumption of the educational services industry sector), while those that employ 20 employees and more consume over 24,000 GWh/year of electricity (71% of total).

The educational services industry sector encompasses a wide array of facilities. One way to classify these facilities is to sub-divide them based upon numbers of employees. Smaller facilities will require less energy than larger ones impacting the ability of fuel cells to be used as a potential alternative to the traditional power sources, the main power grid. Exhibit 6-5 shows a detailed analysis of electricity and heat consumption, along with the emissions produced by the power grid during electricity production. These emissions are calculated assuming a national average (E-Grid database, EIA, 1998) of emissions due to purchased power grid.

The Average Power Demand, listed in the exhibit, is calculated assuming that the electricity is being consumed at a rate of 24 hours a day, 365 days a year, or 8,760 hours per year. It is a measure of the instantaneous power need of a given facility. The average power demand is the primary metric to which the power output of a fuel cell is compared in order to evaluate its suitability for use. All numbers data values presented in Exhibit 6-5 are per year.

**EXHIBIT 6-5: EDUCATIONAL SERVICES INDUSTRY ENERGY CONSUMPTION AND RELATED UTILITY PLANT AIR EMISSIONS FOR 2010**

| Range of Employees | 1 to 4 | 5 to 9 | 10 to 19 | 20 to 49 | 50+ | Total |
|---|---|---|---|---|---|---|
| **Number of Establishments** | 43,605 | 14,776 | 12,383 | 12,653 | 9,470 | 92,889 |
| **Total Electricity Consumption (MWh)** | 2,323,057 | 2,755,034 | 4,947,519 | 11,795,568 | 12,612,526 | 34,433,704 |
| **Average Power Demand (kW)** | 6.1 | 21.3 | 45.6 | 106.4 | 152 | N/A |
| **Total Thermal Consumption (MWh)** | 4,135,041 | 4,903,961 | 8,806,583 | 20,996,111 | 22,450,297 | 61,291,993 |
| **Total $CO_2$ Emissions (million lbs.)** | 3,298 | 3,913 | 7,026 | 16,754 | 17,913 | 48,906 |
| **Total $SO_2$ Emissions (million lbs.)** | 17 | 21 | 38 | 88 | 95 | 259 |
| **Total $NO_x$ Emissions (million lbs.)** | 8 | 10 | 18 | 42 | 45 | 123 |
| **Total Emissions (million lbs.)** | 3,325 | 3,944 | 7,082 | 16,884 | 18,053 | 49,288 |

* N/A: Not applicable, for instance Average Power demand is specific to a single facility.
Note: Average power demand is based on an annual usage of 8,760 hours per year (100%). Power demand represents the average over a one-year period of time, therefore, it does not reflect the actual power demands of a specific establishment or industry (i.e., high demand and low demand).

Emissions generated during electricity production in the U.S. were calculated using a national average of 1420.33 lbs./MWh of $CO_2$, 7.5 lbs./MWh of $SO_2$ and 3.55 lbs./MWh of $NO_x$ from EPA's E-Grid database using power plant emissions factors for the National energy grid. Over the next ten years, the National average for air emissions released from the U.S. production of electricity (electricity grid) will change due to advanced technologies for traditional energy sources and the market penetration of new and distributed generation energy sources. Modeling and prediction of potential changes to future environmental burdens from U.S. energy sources was beyond the scope of this effort, therefore, a level of uncertainty is accepted in the predicted mass of pollution created or avoided.

## 6.3 Fuel Cell Market Potential

The fuel cell market potential is determined by matching the average power demand of each school size class (i.e., 1 to 4, 5 to 9, 10 to19, 20 to 49, 50+) from the industry sector profile (see Section 6.2.3) with the estimated compatibility range of each type of fuel cell (see Chapter 3.0 for an overview of each type of fuel cell). The average power demand is a measure of the instantaneous power need of a given facility. Exhibit 6-6 presents the potential market size for four fuel cell technologies in 2010.

In 2010, all four types of fuel cell technologies (PAFC, PEMFC, SOFC and MCFC) have market potential in the educational services industry. Exhibit 6-6 highlights the potential market size for different fuel cell technologies in 2010 with Y (Yes) indicating where a particular fuel cell technology is expected to be marketable and N (No, if applicable) indicating where there is no potential market. All four fuel cell types have a large potential market size comprising 49,282 educational facilities (53% of the educational services market).

**EXHIBIT 6-6: FUEL CELL MARKET POTENTIAL FOR 2010**

| SCHOOL SIZE CLASS (EMPLOYEES) | NUMBER OF ESTABLISHMENTS | AVERAGE POWER DEMAND (kW) | FUEL CELL TECHNOLOGY & PROJECTED OPERATING RANGE FOR 2010 [A] | | | |
|---|---|---|---|---|---|---|
| | | | PAFC (50 – 250 kW) | PEMFC (50–- 250 kW) | SOFC (50 kW–- 5 MW) | MCFC (250 kW – 5 MW) |
| 1–4 | 43,605 | 6.1 | N | N | N | N |
| 5–9 | 14,776 | 21.3 | Y | Y | Y | N |
| 10–19 | 12,383 | 45.6 | Y | Y | Y | N |
| 20–49 | 12,653 | 106.4 | Y | Y | Y | Y |
| 50+ | 9,470 | 152 | Y | Y | Y | Y |
| Potential Market Size: | | | 49,282 | 49,282 | 49,282 | 49,282 |

[A] In determining fuel cell size compatibility, the projected operating capabilities for 2010 were expanded by reducing the lower range by 50% and increasing the upper range by 500% to account for the ability to operate the fuel cell at 50% capacity or operate 5 fuel cell systems in parallel.

## 6.4 Technical Assessment

The technical feasibility of fuel cells entering the educational services industry sector has been organized into the technical factors presented below. These factors were identified earlier in Chapter 3.0.

- Technology Maturity
- Physical Space Requirements
- Infrastructure Requirements
- Start-up time
- Co-generation Potential
- Fuel Efficiency
- Output Reliability/Consistency
- Fuel Flexibility

Each technical factor is described below with respect to the educational services industry sector. The relative importance of each factor to the sector is denoted by the number of " ì " to right of the heading. One star (minimum) indicates low importance and three stars (maximum) indicates high importance.

### 6.4.1 Technology Maturity ì ì ì

Most educational services facilities perceive power generation to be outside the sphere of their current mission. The maturity of the technology is expected to be a significant factor affecting fuel cell technology acceptance by this industry.

### 6.4.2 Physical Space Requirements ì ì ì

This is not an easy problem to solve as most schools operate in relatively small spaces. In typical educational services facilities, fuel cells could be located nearby, externally, in the basement or in another area of the building.

### 6.4.3 Infrastructure Requirements ì ì

Acceptance by educational facilities of fuel cell technology and related costs are likely to be dependent upon the added costs associated with the transport and storage of natural gas, methane or hydrogen. The needed infrastructure for this delivery is likely to be a relatively significant factor in the acceptance of the technology.

### 6.4.4 Start-up Time ì

It is likely that fuel cells installed at educational services facilities would have to operate continuously in order to minimize the capital cost per unit of power generated. Continuous operation would make start-up time relatively insignificant in the acceptance of the technology.

### 6.4.5 Co-generation Potential ì ì ì

Educational services facilities, much like offices, only need an external source of heat in order to control internal temperature. The ability of fuel cells to use the heat generated in their operation to return heat to the facility can be appreciable in that it will eliminate the need for an alternative source of heat. However, the potential for co-generation is not a crucial factor in the acceptance of the technology. in educational services facilities.

### 6.4.6 Fuel Efficiency i

Since Educational Service facilities do not generate a fuel source onsite, fuel must be provided. Thus, fuel efficiency is not an important factor with regard to acceptance of the technology in educational services facilities.

### 6.4.7 Output Reliability/Consistency i i

The reliability also of the fuel cell units will be a critical factor not only in determining the cost of the power generated, but in determining the viability of fuel cell technology in educational services facilities. Sensitive equipment at university laboratories and other research facilities cannot sustain power variations. Loss of computing capability due to unreliable power would result in some concerns for educational services facilities. Thus, output reliability/ consistency is considered a relatively important factor with regard to acceptance of the technology at educational services facilities.

### 6.4.8 Fuel Flexibility i

Not relevant to the educational services sector since in that fuel is not generated onsite.

## 6.5 Cost Assessment

The purpose of the cost assessment is to determine the financial viability of fuel cells being accepted within the educational services industry sector. In general, fuel cells will be accepted if the cost of operating and maintaining a fuel cell is equal to or less than the cost associated with purchasing energy from a local supplier; *if*, the fuel cell system can improve the reliability (power quality) of electricity for the educational services facilities.

The cost assessment is divided into two parts: 1) the estimated cost savings of purchasing and operating a fuel cell in the educational services industry sector in the year 2010; and 2) a qualitative assessment of the relative importance of various economic factors to the educational services industry sector.

### 6.5.1 Estimated Cost Savings

Information was collected from fuel cell manufacturers to estimate the cost of electricity produced by fuel cells. The cost of electricity includes the installed cost (over a 10 year service life), the fuel purchase cost, and the operation and maintenance costs (O&M). Exhibit 6-7 summarizes the cost of fuel cells for the year 2001 and Exhibit 6-8 summarizes the fuel cell cost predictions for the year 2010. Unlike previous sections in this chapter, fuel cell and/or industry market data representing the year 2001 is presented in conjunction with 2010 predictions due to the significant level of uncertainty in the 2010 cost estimates. The increased level of uncertainty in the cost predictions are based on the lack of maturity and history of fuel cells. The consumption of fuel is estimated at 1,900 $ft^3$/hour of methane as reported by the Energy Research and Development Center (U.S. Army Corps of Engineers) during the EPA Fuel Cell Workshop held in Cincinnati Ohio, June 26–27 2001.

The total cost, as expressed in the rightmost column of both Exhibit 6-7 and Exhibit 6-8, is the sum of the installation cost over 10 years, the O&M cost and the fuel cost.

**EXHIBIT 6-7: ESTIMATES OF OVERALL ANNUAL FUEL CELL COSTS (2001)**

| | AVERAGE INSTALLED COST ($/KW) | AVERAGE INSTALLED COST (¢/KWH) | INSTALLATION COST OVER 10 YEARS (¢/KWH) | O&M COST (¢/KWH) | FUEL COST (¢/KWH) | TOTAL COST (¢/KWH) |
|---|---|---|---|---|---|---|
| PAFC | 2,500 | 28.54 | 2.85 | 1.75 | 5.08 | 9.68 |
| **PEMFC** | 10,000 | 114.16 | 11.42 | 1.75 | 5.08 | 18.25 |
| **SOFC** | 10,000 | 114.16 | 11.42 | 1.5 | 5.08 | 18.00 |
| **MCFC** | 8,000 | 91.32 | 9.13 | 1.5 | 5.08 | 15.71 |

Note: Total cost is the sum of the installed cost over 10 years, O&M costs and fuel costs.

The cost projections for 2010 provided by manufacturers indicate a sharp decline in installed costs, O&M costs, and fuel costs for each fuel cell technology. The combination of all these declines results in an overall decrease in total costs for all fuel cells between 2001 and 2010 of approximately 55 % in average per fuel cell.

**EXHIBIT 6-8: ESTIMATES OF OVERALL ANNUAL FUEL CELL COSTS (2010)**

| | AVERAGE INSTALLED COST ($/kW) | AVERAGE INSTALLED COST (¢/kWh) | INSTALLATION COST OVER 10 YEARS (¢/kWh) | O&M COST (¢/kWh) | FUEL COST (¢/kWh) | Total Cost (¢/kWh) |
|---|---|---|---|---|---|---|
| **PAFC** | 875 | 9.99 | 1.00 | 1.00 | 4.16 | 6.16 |
| **PEMFC** | 1,200 | 13.70 | 1.37 | 1.00 | 4.16 | 6.53 |
| **SOFC** | 1,250 | 14.27 | 1.43 | 1.00 | 4.16 | 6.59 |
| **MCFC** | 1,250 | 14.27 | 1.43 | 1.00 | 4.16 | 6.59 |

Note: Total cost is the sum of the installed cost over 10 years, O&M costs and fuel costs.

The estimated costs saved by utilizing fuel cell technology is derived by subtracting fuel cell costs from electricity prices when provided by a local electricity supplier. The average annual electricity cost for the educational services industry is 8.0 ¢/kW. For the educational services industry, Exhibit 6-9 presents the cost savings associated with utilizing each type of fuel cell technology in 2001 and Exhibit 6-10 presents the cost savings estimated for 2010. Cost savings are only provided for employment size classes that have a market potential for utilizing fuel cells (see Section 6.3, Fuel Cell Market Potential). Cost savings presented in parentheses indicate negative savings which means that the current fuel cell electricity costs exceeds the average annual electricity costs from local electricity suppliers.

**EXHIBIT 6-9: FINANCIAL SAVINGS FROM FUEL CELL IMPLEMENTATION IN THE EDUCATIONAL SERVICES INDUSTRY (2001)**

| SCHOOL SIZE CLASS (EMPLOYEES) | NUMBER OF ESTABLISHMENTS | COST OF ELECTRICITY (¢/kWh) | PAFC (¢/kWh) | PEMFC (¢/kWh) | SOFC (¢/kWh) | MCFC (¢/kWh) |
|---|---|---|---|---|---|---|
| 5–9 | 10,577 | 8.0 | (2) | (10) | (10) | (8) |
| 10–19 | 8,864 | 8.0 | (2) | (10) | (10) | (8) |
| 20–49 | 9,057 | 8.0 | (2) | (10) | (10) | (8) |
| 50+ | 6,779 | 8.0 | (2) | (10) | (10) | (8) |

A direct implementation of fuel cells in the educational services industry sector in 2001 is not economically profitable. Projections provided from manufacturers, as well as energy projections provided by the Energy Information Administration (EIA), provide a more positive economic outlook for implementing fuel cells in the educational services industry sector for the year 2010.

**EXHIBIT 6-10: FINANCIAL SAVINGS FROM FUEL CELL IMPLEMENTATION IN THE EDUCATIONAL SERVICES INDUSTRY (2010)**

| SCHOOL SIZE CLASS (EMPLOYEES) | NUMBER OF ESTABLISHMENTS | COST OF ELECTRICITY (¢/kWh) | PAFC (¢/kWh) | PEMFC (¢/kWh) | SOFC (¢/kWh) | MCFC (¢/kWh) |
|---|---|---|---|---|---|---|
| 5-9 | 14,776 | 8.0 | 1.8 | 1.5 | 1.4 | 1.4 |
| 10-19 | 12,383 | 8.0 | 1.8 | 1.5 | 1.4 | 1.4 |
| 20-49 | 12,653 | 8.0 | 1.8 | 1.5 | 1.4 | 1.4 |
| 50+ | 9,470 | 8.0 | 1.8 | 1.5 | 1.4 | 1.4 |

All four fuel cell technologies are economically feasible choices for the educational services industry with a cost savings in 2010 of up to 1.8 ¢/kWh for PAFC's. This would be equivalent to an annual savings of $440 million/year for all educational services facilities with more than 20 employees in 2010. Extrapolating the cost savings for a PAFC for the estimated market of 49,282 establishments within the Educational Services industry sector results in the potential annual savings for the Educational Services industry sector in 2010 could be $578 million.

### 6.5.2 Economic Factors on Market Penetration

The economic feasibility of fuel cells entering the educational services industry sector has been organized into the economic factors presented below. These factors were identified earlier in Chapter 3.0.

- Acquisition Costs
- Annual O&M Costs

- Other Indirect Costs
- Lead Time
- Service Life
- Annual Revenue from the Sale of Electricity
- Possible Energy Tax Credits/Rebates /Grants
- Emissions Credits

Each economic factor is described below with respect to the educational services industry sector. The relative importance of each factor to the educational services industry sector is denoted by the number of " i " to right of the heading. One star (minimum) indicates low importance and three stars (maximum) indicates high importance.

#### 6.5.2.1 Acquisition Costs i i i

For fuel cells to be used in educational services facilities, the unit cost of power produced must be comparable or less than the cost of power available through other means (i.e., purchased grid power). As a component of the unit cost per kWh produced, acquisition costs will be an important factor in the acceptance of the technology.

#### 6.5.2.2 Annual Operation and Maintenance (O&M) Costs i i i

As a component of the unit cost per kWh produced, annual O&M costs will be an important in the acceptance of the technology in educational services facilities.

#### 6.5.2.3 Other Indirect Costs i i i

As a component of the unit cost per kWh produced, other indirect costs of fuel cells will be an important factor in the acceptance of the technology.

#### 6.5.2.4 Lead Time i

Use of fuel cell technology would be a long term capital improvement that would be permanent in nature. Thus, long lead times would not be a significant factor in the acceptance of the technology in educational services facilities.

#### 6.5.2.5 Service Life i

The educational services industry generally expects electronic equipment to have a useful service life of 5 to 10 years, and other equipment (i.e., housekeeping equipment, etc.) to have a service life of 20 to 30 years. Thus, fuel cells are expected to have a service life similar to other educational services activities. Service life is not expected to be a significant factor in the acceptance of the technology.

#### 6.5.2.6 Annual Revenue from the Sale of Electricity i

Electricity produced by fuel cells at educational services facilities would be consumed onsite. Thus, revenue from the sale of electricity, while possibly an important consideration for a few facilities, will probably not be an important factor for the industry as a whole.

#### 6.5.2.7 Possible Energy Tax Credits/Rebates/Grants i i

Because the decision to employ fuel cell technology at educational services facilities will be primarily economically driven, tax credits/rebates/grants could be an important stimulus to developing the acceptance of the technology.

#### 6.5.2.8 Emissions Credits i

Since a program for emissions credits for employing fuel cell technology do not currently exist, this is not an important factor in the acceptance of the technology.

## 6.6 Environmental Assessment

The purpose of the environmental assessment is to determine the potential reduction in air emissions ($CO_2$, $SO_2$ and $NO_x$) and the conservation of natural resources associated with utilizing fuel cells as the primary energy source in the educational services industry sector as opposed to energy from traditional U.S. energy plants. A qualitative assessment of the environmental factors that influence the marketability of fuel cells is also included as part of the environmental assessment. In general, fuel cells have a large environmental advantage over traditional sources of energy (as represented by the national average for the U.S. energy grid). However, a detailed life-cycle assessment would be necessary to determine the actual environmental benefits of fuel cell technologies compared to the current U.S. energy grid.

The results of the environmental assessment are divided into three parts: 1) pollution avoided ($CO_2$, $NO_x$, $SO_2$); 2) natural resources conserved; and 3) the environmental factors on market penetrations. Each section is described below.

### 6.6.1 Pollution Avoided ($CO_2$, $SO_2$, $NO_x$)

The avoided pollution is determined by subtracting the pollution emitted by fuel cells if they were used as a power source instead of the power grid from the pollution emitted by the power grid based on the electricity consumption of the educational services industry sector. The calculation is as follows:

Pollution Avoided = (Pollution Emitted by the Grid) - (Pollution Emitted by Fuel Cells)

The utilization of fuel cells in general reduces emissions as illustrated by the performance specifications of the different types of fuel cells. Fuel cells produce lower levels of emissions per kWh of electricity compared to the emissions produced by the power grid per kWh of electricity. The "pollution avoided," as mentioned above, was calculated to determine the environmental advantages of fuel cells as an alternative primary source of power. Exhibit 6-11 illustrates the potential magnitude of pollution avoided if fuel cells were fully implemented (100% of the market potential) within the educational services industry sector in the years 2001 and 2010. The percentage of pollution avoided when using fuel cells instead of the main grid is also provided for 2001 and 2010 in Exhibit 6-11.

**EXHIBIT 6-11: POTENTIAL POLLUTION AVOIDED IF FUEL CELLS OBTAINED 100% OF THE MARKET POTENTIAL IN THE EDUCATIONAL SERVICES INDUSTRY SECTOR IN 2001 AND 2010**

| School Size Class (Employees) | 2001 | | 2010 | |
|---|---|---|---|---|
| | POLLUTION AVOIDED (MILLION lbs.) | PERCENT REDUCTION (%) | POLLUTION AVOIDED (MILLION lbs.) | PERCENT REDUCTION (%) |
| 5-9 | 801 | 28 | 1,119 | 28 |
| 10-19 | 1,438 | 28 | 2,009 | 28 |
| 20-49 | 3,429 | 28 | 4,791 | 28 |
| 50+ | 3,666 | 28 | 5,123 | 28 |

Based on the findings in Exhibit 6-11, the use of fuel cells can result in a reduction of pollution by up to 28% with respect to air emissions. A comprehensive analysis of competing fuel cell technologies to traditional energy sources (U.S. energy grid) would be necessary to improve the accuracy of the rough-order-of-magnitude assessment conducted.

### 6.6.2 Calculate Fuel Conserved by Using Fuel Cells in 2001 and 2010

In addition to reducing air emissions, the use of fuel cells reduces the amount of fossil fuels used to generate electricity. In 1999, coal generated 51% of electricity, oil generated 3.2%, natural gas generated 15.3%, nuclear generated 19.7%, hydroelectric sources generated 8.3%, and other sources generated 2.4% (EIA) of the total electricity consumed in the U.S. The proportions are very similar for 1998, and it is reasonable to assume that the same proportions apply to the year 2001. It is possible to calculate the quantities of coal, oil and natural gas that would not be consumed if fuel cells were to be used instead as a primary source of power. Exhibits 6-12 and 6-13 illustrate the potential magnitude of "displaced fuel," or natural resources conserved if fuel cells were fully implemented (almost 100% of the market potential) within the educational services industry sector in the years 2001 and 2010.

**EXHIBIT 6-12: NATURAL RESOURCES CONSERVED IN 2001**

| SCHOOL SIZE CLASS (EMPLOYEES) | NUMBER OF ESTABLISHMENTS | ELECTRICITY CONSUMPTION (MWh/yr) | NATURAL RESOURCES CONSERVED | |
|---|---|---|---|---|
| | | | COAL (MILLION lbs.) | OIL (THOUSAND Gal.) |

| | | | | |
|---|---|---|---|---|
| 5-9 | 10,577 | 1,972,108 | 898 | 6,194 |
| 10-19 | 8,864 | 3,541,531 | 1,613 | 11,124 |
| 20-49 | 9,057 | 8,443,499 | 3,845 | 26,521 |
| 50+ | 6,779 | 9,028,294 | 4,112 | 28,357 |

Natural gas being used by the fuel cells is not taken into account in this table.

**EXHIBIT 6-13: NATURAL RESOURCES CONSERVED IN 2010**

| SCHOOL SIZE CLASS (EMPLOYEES) | NUMBER OF ESTABLISHMENTS | ELECTRICITY CONSUMPTION (MWh/yr) | NATURAL RESOURCES CONSERVED | |
|---|---|---|---|---|
| | | | COAL (MILLION lbs.) | OIL (THOUSAND Gal.) |
| 5-9 | 14,776 | 2,755,034 | 1,214 | 8,653 |
| 10-19 | 12,383 | 4,947,519 | 2,181 | 15,540 |
| 20-49 | 12,653 | 11,795,568 | 5,201 | 37,049 |
| 50+ | 9,470 | 12,612,526 | 5,561 | 39,615 |

Natural gas being used by the fuel cells is not taken into account in this table.

Exhibit 6-14 shows the amount of natural gas consumed when fuel cells are implemented in the educational services industry, the amount of natural gas displaced by not using current energy sources, and the resulting net increase in natural gas consumption. This figure does not include the natural gas displaced by using the heat from the fuel cell.

**EXHIBIT 6-14: NATURAL GAS CONSUMED AND CONSERVED WHEN USING FUEL CELLS IN 2010**

| SCHOOL SIZE CLASS (EMPLOYEES) | AVERAGE POWER DEMAND (kW) | NATURAL GAS CONSUMED (MILLION cu. ft.) | NATURAL GAS DISPLACED (MILLION cu. ft.) | NET NATURAL GAS (MILLION cu. ft.) |
|---|---|---|---|---|
| 5-9 | 30 | 22,130 | 2,493 | (19,637) |
| 10-19 | 64 | 48,238 | 4,477 | (43,761) |
| 20-49 | 149 | 84,058 | 10,674 | (73,383) |
| 50+ | 212 | 119,599 | 11,414 | (108,185) |

### 6.6.3 Environmental Factors for Market Penetration

The key environmental factors associated with fuel cells entering the educational services industry sector have been organized into the environmental factors presented below. These factors were identified earlier in Chapter 3.0.

- Air Emissions
- Wastewater Production
- Solid Waste Production
- Resource Usage
- Life-Cycle Related Benefits

Each environmental factor is qualitatively described below with respect to the educational services industry sector. The relative importance of each factor to the educational services industry sector is denoted by the number of " i " to right of the heading. One star (minimum) indicates low importance and three stars (maximum) indicates high importance.

#### 6.6.3.1 Air Emissions i i

Air emissions due to educational services facilities come almost exclusively from the emissions produced by the power grid during electricity production. Since using fuel cell technology can show a positive reduction in associated air emissions, this is an important factor in evaluating potential fuel cell use.

#### 6.6.3.2 Wastewater Production i

No significant quantities of wastewater emissions are expected to be generated by fuel cells. Thus wastewater generation is not expected to be an important factor with regard to acceptance of the technology.

#### 6.6.3.3 Solid Waste Production i

Solid waste generation from fuel cells generally consists of non-hazardous materials (i.e., filter cartridges), and spent catalysts, which can be reclaimed and recycled. Solid waste generation for other types of fuel cells is expected to be similar and is comparable on a per unit basis to the waste generated by the power grid. Thus, solid waste generation is not expected to be an important factor in the acceptance of the technology in educational services facilities.

#### 6.6.3.4 Resource Usage i i

The principal resource required as a feedstock for the fuel cells is a gas hydrocarbon fuel. Such a feedstock will have to be purchased as it cannot possibly be produced onsite. Because of the added costs associated with the purchase of feedstock, resource usage is anticipated to be a relatively important factor in the acceptance of the technology.

#### 6.6.3.5 Life-Cycle Related Benefits i i

Fuel cell technology is considered to be almost pollution free during its operation (minimal $CO_2$, $SO_2$ and $NO_x$ ; cooling/rinse water, and negligible solid waste). In terms of downstream end-of-life impacts, most manufacturers are reporting that they expect the majority of the fuel cell components to be recyclable (95% by weight according to IFC). Most of the remaining 5% are anticipated to be landfilled, with less than one percent being hazardous waste (heavy metal wastes from the cell and/or ancillary fluids). Since very few fuel cells have been decommissioned to date, these end-of-life estimates need to be revised as substantiating data become available. In terms of upstream impacts, the life cycle impacts are anticipated to be those common to manufacturing/assembly activities (e.g., structural frame, plumbing, and insulation) including solvents and chemicals from metal processing, paints and coatings, and associated other assembly/production by-products. Thus, compared to electricity produced by the power grid, life-cycle related benefits are anticipated to be relatively important factors in the acceptance to acceptance of the technology in the educational services industry.

## 6.7 Institutional Considerations

Institutional considerations affecting the marketability of fuel cells in the educational services industry sector have been organized into the factors presented below. These factors were identified earlier in Chapter 3.0.

- Regulatory Barriers
- Market/Customer Acceptance
- Staff Experience/Training Required

Each institutional factor is described below with respect to the educational services industry sector. The relative importance of each factor to the educational services industry sector is denoted by the number of “ i ” to right of the heading. One star (minimum) indicates low importance and three stars (maximum) indicates high importance.

### 6.7.1 Regulatory Barriers i

Because fuel cells are an emerging technology, regulatory standards and codes have not yet been developed. As fuel cells gain greater acceptance in this, and other industries, appropriate codes and standards will likely emerge. Thus, regulatory barriers are not anticipated to be an important factor in the acceptance of the technology.

### 6.7.2 Market/Customer Acceptance
i i

The market/customer acceptance relates to how receptive and motivated a customer is to use a fuel cell system in place of its current sources of power. This particular factor includes reviewing what the customer has invested in providing and maintaining the current power sources (which is linked to the economic factors), the willingness of a customer to utilize cutting-edge innovative technology, and for this particular sector, how the public will value and balance other benefit factors (such as the environmental) in deciding whether to use fuel cell technology.

### 6.7.3 Staff Experience/Training Required
i i i

While the fuel cells themselves may be relatively simple to operate, the gas conditioning processes needed for both PAFC and PEMFC technologies may require O&M skills that may not be found at educational services facilities. Thus, staff expertise and the training needed will be a significant factor in the acceptance of fuel cell technology in schools.

## 6.8 Summary of Fuel Cell Opportunities in the Educational Services Industry Sector

As the student population in the nation's schools and universities continues to grow, the demand and costs of energy to support the increasing student population will increase as well. Additionally, an effort to improve student performance and accommodate the growing student population,

**Exhibit 6-15: Summary of Factors Influencing Marketability of Fuel Cells in the Educational Services Industry Sector**

| Technical Factors | |
|---|---|
| Technology maturity | i i i |
| Physical space requirements | i i i |
| Infrastructure requirements | i i |
| Start-up time | i |
| Co-generation options | i i i |
| Fuel efficiency | i |
| Output reliability/consistency | i i |
| Fuel flexibility | i |
| **ECONOMIC FACTORS** | |
| Acquisition costs (purchase and installation) | i i i |
| Annual operation and maintenance costs | i i i |
| Lead Time | i |
| Other annual indirect costs (e.g., liability, environmental) | i i i |
| Service life | i |
| Annual revenue from sale of output | i |
| Annual business energy tax credits/rebates (Federal, State, local) | i i |
| Emissions credits | i |
| **ENVIRONMENTAL FACTORS** | |
| Air emissions | i i |
| Wastewater releases | i |
| Solid waste (non-hazardous and hazardous) | i |
| Resource usage (water, fuel feedstock) | i i |
| Life-Cycle related benefits | i i |
| **INSTITUTIONAL FACTORS** | |
| Regulatory barriers | i |
| Management/customer acceptance | i i |
| Staff expertise/training required | i i |

i i i - 3 Stars denote factors critical to marketability in the Educational Services Industry sector.

many schools are expanding school hours, shifting toward year round classes, providing individual instruction, smaller classes and computer-based training/education. Unfortunately, these and other measures have the disadvantage of increasing energy consumption and associated costs, making the need for alternative sources of energy consumption a more pressing concern. A significant number of U.S. schools, particularly K-12, spend an excess of $6 million a year on energy. In light of these exorbitant expenditures, many schools are looking for more creative ways to save resources on energy expenditures. DOE's Energy Smart School program, EPA's Energy Star program, and the Rebuild America program are examples of public, and public-private and community partnerships and programs designed to facilitate building improvements and costs savings through implementing energy efficient measures.

Fuel cells are one of several distributed generation technologies that will play a key role in meeting the increasing energy demands of schools and universities. The introduction of fuel cell technology in the educational services industry as an alternative to the electric power grid is growing in acceptance because of the promising environmental and economic benefits offered in the present but particularly in the future. Fuel cells are an environmentally-friendly energy source and wide-scale adoption will have a significant affect in reducing the releases of greenhouse gases while preserving natural resources (i.e., coal, oil, natural gas, etc.).

Although quite promising, unfortunately, the current costs of fuel cell technology are very high which has prevented its penetration of the market. The relative importance of cost and other factors (e.g., technical, environmental and acceptance factors) that will influence the marketability of fuel cells in the educational services support industry sector is presented in Exhibit 6-15. The relative importance of each factor to the educational services industry sector is denoted by the number of " l " to right of the heading. One star (minimum) indicates low importance and three stars (maximum) indicates high importance.

The results of this study indicate that in 2010, the PAFC, PEMFC, SOFC and MCFC technologies can be utilized within the educational services industry sector comprising a potential market size of 49,282 educational services establishments 53% of the educational services market. Those establishments with the largest number of employees are most likely to benefit from the fuel cell technology.

The maturity of the fuel cell technology is expected to be a significant factor affecting fuel cell technology acceptance. Additionally, educational services facilities require both thermal and electrical power. The reliability of the fuel cell units will not be a critical factor in determining the viability of fuel cell technology in educational services facilities, but equipment at educational services facilities can be sensitive to power variations.

For fuel cells to be used at educational services facilities, the unit cost of power they produce must be comparable or less than the cost of power available through other means (i.e., purchased grid power). As a component of the unit cost per kWh produced, acquisition costs and annual O&M costs as well as other indirect costs of fuel cells will be an important factor in the acceptance of the technology in educational services facilities. In terms of financial savings, utilizing manufacturers' projections for 2010, a sharp decline in installed costs, O&M costs, and fuel costs for each fuel cell technology results an overall decrease in fuel cell costs from 2001 of 55% per average fuel cell. In 2010 an estimated financial savings of $578 million is expected if fuel cell technologies are implemented.

Air emissions due to educational services facilities come exclusively from the emissions produced by the power grid during electricity production. Since using fuel cell technology reduces the generation of associated air emissions ($CO_2$, $SO_2$ and $NO_x$), this is an important factor in evaluating potential fuel cell use. In 2010, schools utilizing fuel cell technologies are expected to generate a total of 32,921 million lbs. of energy-related emissions, instead of the expected 45,963 million lbs. of power grid-related emissions. This represents a reduction of 28 percent.

A gas hydrocarbon fuel is typically used as a feedstock for fuel cells. Because of the added costs associated with purchase of feedstock, resource usage is expected to be a relatively important factor in the acceptance of the technology in educational services facilities. However, data collected for this study indicate that the conservation of natural resources resulting from the use of fuel cells far outweighs the associated cost of purchasing fuel for the use in the fuel cell. For example, the use of fuel cells in 2010 will result in the conservation of 8,812 million lbs. of coal and 3,228 thousand gallons of oil.

Another concern regarding the acceptance of fuel cells is staff expertise and training needed to ensure the efficient operation of the fuel cell. The fuel cells themselves are relatively simple to operate, however, the gas conditioning processes needed for both fuel cell technologies may require O&M skills that may or may not be found in educational services facilities where sensitive and complex equipment is sometimes used on a daily basis. Consequently, there may be some costs associated with hiring and training staff to operate the fuel cells.

In spite of the various technical, economic and environmental factors discussed, the educational services industry requires an economical, clean and reliable power source as an alternative to the electrical power grid. The fuel cell technologies identified in this report may offer the source of power to support the energy needs of this industry sector while offering significant environmental benefits. Opportunities to integrate fuel cells could occur through the construction of new schools. Unfortunately, most new schools are not energy efficient. Although some incorporate "modest" energy efficient measures, most do not. The cost savings that will result from the implementation of fuel cells and other energy efficient measures can be applied toward the purchase of needed supplies, books, recreational programs and salaries.

# 7.0 Hospital Industry Sector Analysis

As a result of the industry prioritization (see Chapter 4.0), the hospital industry sector ranked in the First (top) tier with a fuel cell market potential of 7,317 establishments estimated for the year 2010 or 95% of the total market based on the fuel cell compatibility of their average power demand. The Hospital industry was also selected based on its relatively high energy usage, need for both thermal and electrical energy, current use, and familiarity with on-site energy generation to support on-going activities.

The purpose of this chapter is to provide a detailed analysis of the potential market for fuel cells in the year 2010 within the hospital industry sector. The results of the detailed analysis have been divided into the following eight areas:

- Definition of the Hospital Industry Sector — Section 7.1
- Industry Sector Profile for 2010 — Section 7.2
- Fuel Cell Market Potential — Section 7.3
- Technical Assessment — Section 7.4
- Cost Assessment — Section 7.5
- Environmental Assessment — Section 7.6
- Institutional Considerations — Section 7.7
- Summary of Fuel Cell Opportunities in the Hospital Industry Sector — Section 7.8

Each area is described in detail below.

## 7.1 Definition of Hospital Industry Sector

The hospital industry sector is defined by the North American Industry Classification System (NAICS) as section 622, "Hospitals." Hospitals are also classified as Inpatient Health Care facilities by the Department of Energy's Energy Information Administration's (EIA) Commercial Buildings Energy Consumption Survey (CBECS). Each definition is provided below.

### 7.1.1 NAICS Code: 622 Hospitals

Facilities in the Hospitals sector are comprised of sub-sectors that provide medical, diagnostic, and treatment services that include physician, nursing, and other health services to inpatients and the specialized accommodation services required by inpatients. Hospitals may also provide outpatient services as a secondary activity. Establishments in the Hospitals sub-sector provide inpatient health services many of which can only be provided using the specialized facilities and equipment that form a significant and integral part of the production process. The Hospital industry sector defined as NAICS 622 includes the following sub-sectors:

- 6221 General Medical and Surgical Hospitals
- 62211 General Medical and Surgical Hospitals
- 622110 General Medical and Surgical Hospitals
- 6222 Psychiatric and Substance Abuse Hospitals
- 62221 Psychiatric and Substance Abuse Hospitals
- 622210 Psychiatric and Substance Abuse Hospitals
- 6223 Specialty (except Psychiatric and Substance Abuse) Hospitals
- 62231 Specialty (except Psychiatric and Substance Abuse) Hospitals
- 622310 Specialty (except Psychiatric and Substance Abuse) Hospitals

Source: U.S. Census Bureau, www.census.gov/epcd/naics; NAICS Association, www.naics.com

### 7.1.2 Commercial Buildings Energy Consumption Survey (CBECS)

One approach for profiling the energy usage of the Hospital sector is by utilizing the Commercial Buildings Energy Consumption Survey (CBECS) which is a national sample survey that collects statistical information on the consumption of and expenditures for energy in U.S. commercial buildings along with data on energy-related characteristics of the buildings. CBECS is conducted by the Energy Information Administration (EIA) of the U.S. Department of Energy. The CBECS survey has been conducted triennially since 1983. Complete data are available for the 1995 survey while preliminary data has currently been released for the 1999 survey (number of buildings and square footage data only).

> Health Care: Refers to buildings used as diagnostic and treatment facilities for both inpatient and outpatient care. Inpatient facilities treat the mentally or physically ill. Buildings for overnight care are in this grouping. Excluded from this group are skilled nursing or other residential care facilities (nursing homes) and Outpatient facilities. Outpatient care may be medical, dental, or psychiatric and involves diagnosis and treatment in which services are not required overnight. Buildings used for veterinary practices would also be included in this category.
>
> Source: http://www.eia.doe.gov/emeu/cbecs/buildingtypes.html, “CBECS Description of Building Types”

In the CBECS, buildings are classified according to principal activity, which was the primary business, commerce, or function carried on within each building. As part of the CBECS, data are collected on buildings classified by the activity of “Health Care.” This classification includes both inpatient and outpatient facilities. Only inpatient facilities are included in the Hospital industry sector as defined in this report.

Specifically, the CBECS collects data on the following types of inpatient health care facilities:

***1. Medical Care Hospital:***

- Chronic disease
- Ear, eye, nose, and throat
- General medical and surgical
- Maternity
- Medical infirmary (connected with an institution)
- Orthopedic
- Tuberculosis/other respiratory disease

***2. Mental Facility:***

- Mental retardation/schools for the mentally retarded
- Psychiatric

***3. Rehabilitation Facility:***

- Alcoholism
- Substance abuse/narcotics/drug addiction
- Physical therapy

## 7.2 Industry Sector Profile for 2010

The results for the year 2010 industry sector profile of the hospital industry were estimated by extrapolating historical data using an estimated growth rate for the industry while holding other factors constant. Understanding the foundation of the industry sector profile is important to understanding the uncertainty in the results and properly interpreting and communicating the results in a transparent manner. The methodology used to generate the hospital industry sector profile for 2010 is explained below.

### 7.2.1 Methodology

Publically available data characterizing the hospital industry sector (number of employees per establishment) in 1998 were combined with detailed energy statistics (amount of energy consumed per employee) in 1995 to estimate the electrical and thermal demand of small, medium, and large hospitals in the United States (U.S.). The amount of energy consumed per employee in a hospital was assumed to be constant between 1995 and 1998 in correlating the data to determine the average power demand, total energy consumption (relative to the U.S. electrical grid), and the pounds of air emissions released from U.S. power plants (based on 1998 E-Grid data) as a result of the amount of energy consumed by small, medium, and large hospitals in 1998.

The results were scaled from the present to 2010 by assuming a 1% annual growth in the hospital industry sector. The growth rate was determined by analyzing the U.S. Census Bureau's County Business Patterns (CBP) data for the growth rate in the number of establishments in the hospital industry sector from 1998 to 1999 and the EIA Annual Energy Outlook for the hospital industry to 2020. The results of the industry growth analysis indicated an average growth rate of 0.1% based on CBP data, while EIA's Annual Energy Outlook estimated an increase of 2.9 % in power consumption; therefore, an average rate of 1% was used to scale the market analysis from the present to 2010. To accomplish this goal, the number of establishments (small, medium, and large) was increased annually by the growth rate while the following variables were assumed to remain constant:

- Amount of energy consumed per hospital employee
- Distribution of small, medium, and large hospitals within the industry sector
- Emissions profile from the US electricity grid was assumed to remain constant per kilowatt (kW) of power consumed.

### 7.2.2 Size of Industry Sector

According to the 1999 CBP, 6,960 establishments comprised NAICS Code 622, Hospitals. Applying a 1% annual growth factor, the total number of hospital establishments is estimated to be 7,688 establishments in 2010. Hospital establishments are evenly distributed across the U.S. with respect to the total population of each state (see Exhibit 7-1). Approximately 46% of the hospital establishments are located in 10 states. The top four are California, Texas, Florida and New York; see Exhibit 7-2 for a list of the top 10 states with the most hospital establishments. The list of top 10 states represents the states with the greatest market potential based on the number of establishments only.

**EXHIBIT 7-1: GEOGRAPHICAL DISTRIBUTION OF HOSPITAL ESTABLISHMENTS ACROSS THE UNITED STATES IN 2010**

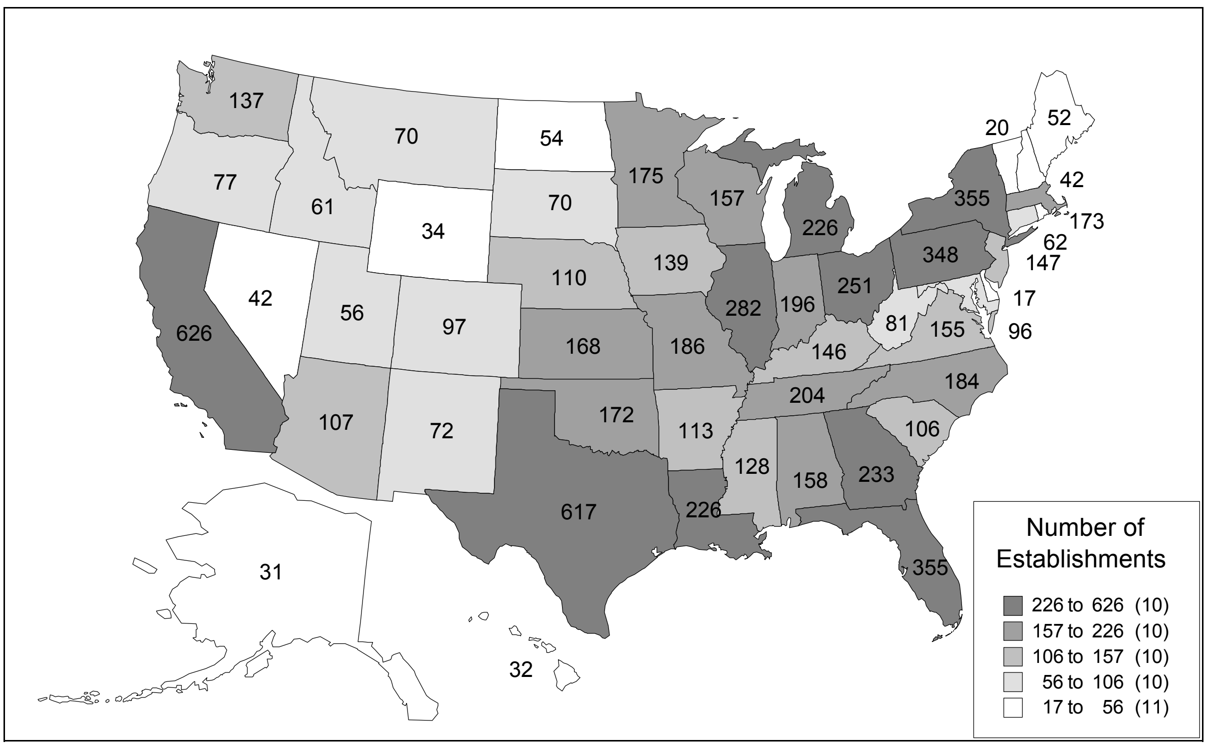


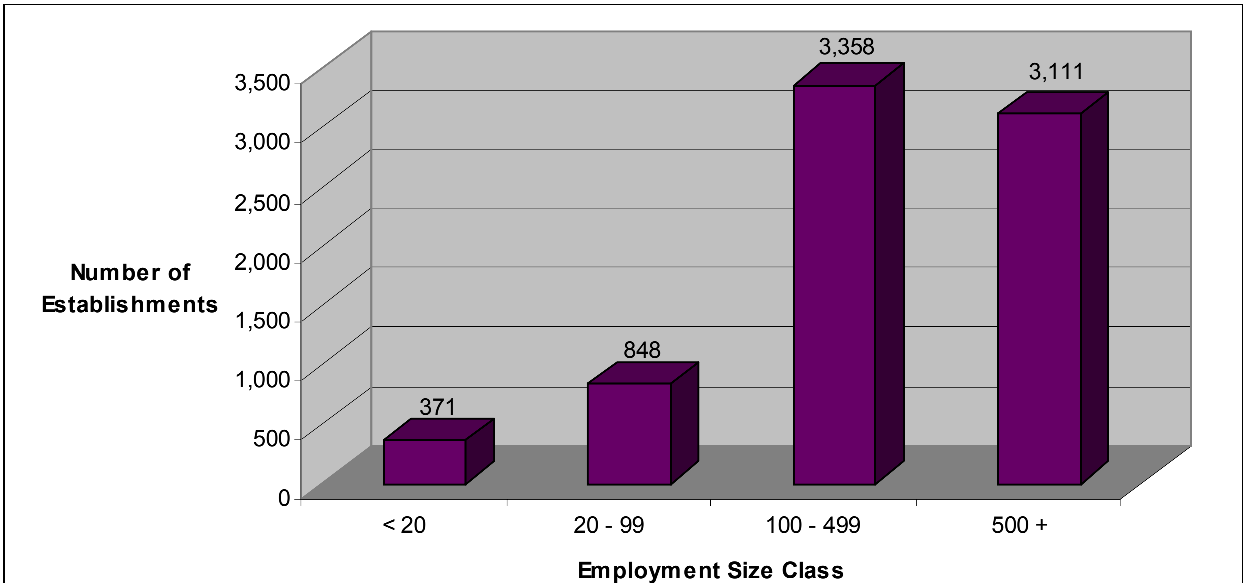
**EXHIBIT 7-2: NUMBER OF HOSPITAL ESTABLISHMENTS FOR THE TOP TEN STATES IN 2010**

| STATE | NUMBER OF ESTABLISHMENTS[A] | PERCENT (%) OF TOTAL ESTABLISHMENTS[B] |
|---|---|---|
| California | 626 | 8.1 |
| Texas | 617 | 8.0 |
| Florida | 355 | 4.6 |
| New York | 355 | 4.6 |
| Pennsylvania | 348 | 4.5 |
| Illinois | 282 | 3.7 |
| Ohio | 251 | 3.3 |
| Georgia | 233 | 3.0 |
| Louisiana | 226 | 2.9 |
| Michigan | 226 | 2.9 |
| *Subtotal* [C] | 3,510 | 45.8 |
| Other [D] | 4,170 | 54.2 |
| *Total* [E] | 7,689[F] | 100 |

[A] Represents the number of hospitals in each state.
[B] Equals the number of facilities in a state divided by the Total and then multiplied by 100.
[C] Equals the sum of the facilities in the 10 states with the highest number of facilities.
[D] Equals the sum of the facilities in the remaining 40 states.
[E] Equals the sum of the facilities in the entire United States.
[F] Actual total number of hospital establishments estimated for 2010 is 7,688. Additional one (1) establishment results from differences in rounding when escalating.

Establishments within the hospital industry sector can roughly be divided into four employment size classes; <20, 20 to 99, 100 to 499, and 500+ employees respectively. Exhibit 7-3 illustrates the distribution of establishments relative to employee size. As illustrated in the exhibit, the hospital industry sector consists primarily of mid- to large-size establishments with approximately 44% having between 100 and 499 employees and 43% having greater than 500 employees.

**EXHIBIT 7-3: DISTRIBUTION OF ESTABLISHMENTS BY EMPLOYMENT SIZE CLASS FOR THE HOSPITAL INDUSTRY IN 2010**




Source: 1998 County Business Pattern, NAICS Code 622; escalated at 1% annually.

### 7.2.3 Annual Energy Consumption and Related Utility Plant Air Emissions

Based on the EIA's 1995 Commercial Building Survey Data, inpatient health care facilities consume an average of 26.5 kWh per square foot of building space and average 541 square foot of floor space per worker. This converts into a site electricity consumption rate of 14,337 kWh/employee. The average electricity consumption of a hospital per number of employees is estimated in Exhibit 7-4.

Hospitals consume both electric and thermal energy to provide heating and cooling and electricity to operate equipment, lights, etc. Based on the 1995 Commercial Building Survey, inpatient health care facilities (i.e., hospitals) consume 163% more thermal energy than electricity. This is consistent with the high heating and cooling demands of large buildings. The thermal demand for the hospital industry with respect to establishment employee size class is provided in Exhibit 7-4.

Complementing the industry sector profile in Exhibit 7-4 is an estimate of the pounds of $CO_2$, $SO_2$ and $NO_x$ predicted to be released from U.S. power plants as a result of the quantity of electricity consumed by the hospital industry. These data will be used as the basis for estimating the air pollutant releases avoided through the use of environmentally friendly distributed generation (see Section 7.6, Environmental Assessment).

**EXHIBIT 7-4: HOSPITAL INDUSTRY ENERGY CONSUMPTION AND RELATED UTILITY PLAN AIR EMISSIONS FOR 2010**

| NUMBER OF EMPLOYEES | <20 | 20–99 | 100–499 | 500+ | TOTAL |
|---|---|---|---|---|---|
| **Number of Establishments** | 371 | 848 | 3,358 | 3,111 | 7,688 |
| **Total Electricity Usage (MWh/year)** | 53,223 | 729,920 | 14,446,337 | 31,224,362 | 46,453,842 |
| **Average Power Demand (kW)*** | 16 | 98 | 491 | 1,162 | N/A |
| **Total Thermal Consumption (MWh)** | 86,754 | 1,189,770 | 23,547,529 | 50,895,711 | 75,719,764 |
| **Total $CO_2$ Emissions (million lbs./yr)** | 75.6 | 1,036 | 20,518 | 44,349 | 66,980 |
| **Total $SO_2$ Emissions (million lbs./yr)** | 0.4 | 5.5 | 108 | 234 | 348 |
| **Total $NO_x$ Emissions (million lbs./yr)** | 0.2 | 2.6 | 51.3 | 111 | 165 |
| **Total Emissions (million lbs./yr)** | 76.2 | 1,044 | 20,678 | 44,694 | 66,493 |

Note: * Average power demand is based on an annual usage of 8,760 hours per year (100%). Power demand represents the average over a one-year period of time, therefore, it does not reflect the actual power demands of a specific establishment or industry (i.e., high demand and low demand).

Emissions produced during electricity production in the U.S. were calculated using a national average of 1420.33 lbs./MWh of $CO_2$, 7.5 lbs./MWh of $SO_2$ and 3.55 lbs./MWh of $NO_x$ as derived from EPA's E-Grid database using power plant emissions factors for the National energy grid. Over the next ten years, the National average for air emissions released from the U.S. production of electricity (electricity grid) will change due to advanced technologies for traditional energy sources and the market penetration of new and distributed generation energy sources. Modeling and prediction of potential changes to future environmental burdens from U.S. energy sources was beyond the scope of this effort; therefore, a level of uncertainty is accepted in the predicted mass of pollution created or avoided.

## 7.3 Fuel Cell Market Potential

The fuel cell market potential is determined by matching the average power demand of each employment size class (i.e., <20, 20 to 99, 100 to 499, and 500+) from the industry sector profile (see Section 7.2.3) with the estimated compatibility range of each type of fuel cell (see Chapter 3.0 for an overview of each type of fuel cell). The average power demand is calculated assuming that the electricity is being consumed at a rate of 24 hours a day, 365 days a year, or 8,760 hours per year. It is a measure of the instantaneous power need of a given facility. Exhibit 7-5 highlights the potential market size for different fuel cell technologies in 2010, with Y (Yes) indicating where a particular fuel cell technology is expected to be marketable and N (No) indicating where there is no potential market.

All four types of fuel cell technologies have market potential in the hospital industry with respect to the projected operating ranges available in 2010 matching the energy demands of the industry. PAFC, PEMFC, and SOFC have the greatest potential market size comprising 7,317 hospital establishments (95% of the hospital market) while the MCFC potential market is slightly reduced due to the less broad operating range of this technology. However, both MCFC and SOFC fuel cells have a competitive advantage over the other types of technology due to their ability to produce both electricity and high temperature thermal energy, better matching the energy needs of the hospital market.

**EXHIBIT 7-5: FUEL CELL MARKET POTENTIAL IN 2010**

| EMPLOYMENT SIZE CLASS | NUMBER OF ESTABLISHMENTS | AVERAGE POWER DEMAND (KW) | FUEL CELL TECHNOLOGY & PROJECTED OPERATING RANGE FOR 2010 [A] | | | |
|---|---|---|---|---|---|---|
| | | | PAFC (50–250 kW) | PEMFC (50–250 kW) | SOFC (50 kW – 5 MW) | MCFC (250 kW – 20 MW) |
| < 20 | 371 | 16 | N | N | N | N |
| 20–99 | 848 | 98 | Y | Y | Y | N |
| 100–499 | 3,358 | 491 | Y | Y | Y | Y |
| 500 + | 3,111 | 1,162 | Y | Y | Y | Y |
| | | Potential Market Size: | 7,317 | 7,317 | 7,317 | 6,469 |

[A] In determining fuel cell size compatibility, the projected operating capabilities for 2010 were expanded by reducing the lower range by 50% and increasing the upper range by 500% to account for the ability to operate the fuel cell at 50% capacity or operate 5 fuel cell systems in parallel.

## 7.4 Technical Assessment

This section evaluates the technical feasibility of using fuel cell technology within the hospitals industry. The technical feasibility of fuel cells entering the hospital industry sector has been organized into the technical factors presented below. These factors were identified earlier in Chapter 3.0.

- Technology Maturity
- Physical Space Requirements
- Infrastructure Requirements
- Start-up time
- Co-generation Potential
- Fuel Efficiency
- Output Reliability/Consistency
- Fuel Flexibility

Each technical factor is described below with respect to the hospital industry sector. The relative importance of each factor to the hospital industry sector is denoted by the number of " ì to right of the heading. One star (minimum) indicates low importance and three stars (maximum) indicates high importance.

### 7.4.1 Technology Maturity ì ì ì

Most health care facilities perceive power generation to be outside the sphere of their current mission. The maturity of the technology is expected to be a significant factor affecting fuel cell technology acceptance within the hospital industry sector.

### 7.4.2 Physical Space Requirements ì ì ì

A 200 kW PAFC requires a 6 foot by 4 foot footprint and can be mounted in a room with a standard ceiling height. Depending on the specific energy requirements (electricity and/or thermal) and energy demand (50 kW or 5 MW) the space requirements will vary greatly. In most cases, hospitals are located in areas that are not conducive to building expansion and existing space is limited; therefore, physical space requirements is a significant factor to acceptance in the hospital industry sector.

### 7.4.3 Infrastructure Requirements i

Natural gas, a commonly available utility service at hospitals (except in select areas where natural gas service is not available), is the primary fuel choice for operating fuel cells. Therefore, physical space requirements (see Section 7.4.2 above) is anticipated to be the only infrastructure oriented limitation.

### 7.4.4 Start-up Time i

Start-up time is not a limiting technical factor in the hospital industry sector because hospitals operate on a 24-hour basis which is the preferred operating mode for fuel cells.

### 7.4.5 Co-generation Potential i i

Mid to large size hospitals have a significant co-generation potential. According to the EIA's 1995 Commercial Building Energy Consumption Survey, water and space heating (thermal energy needs) consist of 49% of the total energy consumed by hospitals. Hospital co-generation or thermal energy requirements are classified as "high" temperature. Two of the four fuel cell technologies reviewed in this report are projected to produce "high" temperature thermal energy, solid oxide fuel cells (SOFC) and molten carbonate fuel cells (MCFC).

### 7.4.6 Fuel Efficiency i

Fuel can only be purchased for conversion to heat and electricity in hospitals as it cannot be produced onsite. Thus, except for economical reasons, fuel efficiency is not an important factor in the acceptance of the technology in the hospital industry sector.

### 7.4.7 Output Reliability/Consistency i i i

The reliability of the fuel cell units will be a factor not only in determining the cost of the power generated, but also most importantly in determining the viability of fuel cell technology in health care facilities. Human lives depend on the correct operation of sensitive equipment that cannot sustain significant power fluctuations or unexpected power failure. Therefore, output reliability/consistency is an important factor in the acceptance of the technology.

### 7.4.8 Fuel Flexibility

i

Fuel flexibility is not a significant technical factor because fuel (natural gas) would be purchased from a supplier as opposed to generated onsite.

## 7.5 Cost Assessment

The purpose of the cost assessment is to determine the financial viability of fuel cells being accepted within the hospital industry sector. In general, fuel cells will be accepted if the cost of operating and maintaining a fuel cell is equal to or less than the cost associated with purchasing energy from a local supplier; *if*, the fuel cell system can improve the reliability (power quality) of electricity.

The cost assessment is divided into two parts: 1) the estimated financial savings of purchasing and operating a fuel cell in the hospital industry sector in 2010; and 2) a qualitative assessment of the relative importance of various economic factors to the hospital industry sector.

### 7.5.1 Estimated Financial Savings

Information was collected from fuel cell manufacturers to estimate the cost of electricity produced by fuel cells. The cost of electricity includes the installed cost (over a 10-year service life), the fuel purchase cost, and the operation and maintenance costs (O&M). Exhibit 7-5A summarizes the cost of fuel cells for the year 2001 and Exhibit 7-6 summarizes the fuel cell cost predictions for the year 2010. Unlike previous sections in this Chapter, fuel cell and/or industry market data representing the year 2001 is presented in conjunction with 2010 predictions due to the significant level of uncertainty in the 2010 cost estimates. The increased level of uncertainty in the cost predictions are based on the lack of maturity and history of fuel cells implementation.

**EXHIBIT 7-5A: ESTIMATES OF OVERALL ANNUAL FUEL CELL COSTS (2001)**

| | AVERAGE INSTALLED COST ($/KW) | AVERAGE INSTALLED COST (¢/KWH) | INSTALLED COST OVER 10 YEARS (¢/KWH) | O&M COST (¢/KWH) | FUEL COST (¢/KWH) | TOTAL COST (¢/KWH) |
|---|---|---|---|---|---|---|
| **PAFC** | 2,500 | 28.54 | 2.85 | 1.75 | 5.08 | 9.68 |
| **PEMFC** | 10,000 | 114.16 | 11.42 | 1.75 | 5.08 | 18.25 |
| **SOFC** | 10,000 | 114.16 | 11.42 | 1.5 | 5.08 | 18.00 |
| **MCFC** | 8,000 | 91.32 | 9.13 | 1.5 | 5.08 | 15.71 |

Note: Total cost is the sum of the installed cost over 10 years, O&M costs and fuel costs.

The cost projections for 2010 provided by manufacturers indicate a sharp decline in installed costs, O&M costs, and fuel costs for each fuel cell technology. The combination of these declines results in an overall decrease in total costs for all fuel cells between 2001 and 2010 averaging approximately 55% per fuel cell.

**EXHIBIT 7-6: ESTIMATES OF OVERALL ANNUAL FUEL CELL COSTS (2010)**

| | AVERAGE INSTALLED COST ($/KW) | AVERAGE INSTALLED COST (¢/KWH) | INSTALLED COST OVER 10 YEARS (¢/KWH) | O&M COST (¢/KWH) | FUEL COST (¢/KWH) | TOTAL COST (¢/KWH) |
|---|---|---|---|---|---|---|
| **PAFC** | 875 | 9.99 | 1.00 | 1.00 | 4.16 | 6.16 |
| **PEMFC** | 1,200 | 13.70 | 1.37 | 1.00 | 4.16 | 6.53 |
| **SOFC** | 1,250 | 14.27 | 1.43 | 1.00 | 4.16 | 6.59 |
| **MCFC** | 1,250 | 14.27 | 1.43 | 1.00 | 4.16 | 6.59 |

Note: Total cost is the sum of the installed cost over 10 years, O&M costs and fuel costs.

The estimated costs saved by utilizing fuel cell technology is derived by subtracting fuel cell costs from electricity prices provided by a local electricity supplier. The average annual electricity cost, for the hospital industry, is 6.3 ¢/kW (EIA). Exhibit 7-7 presents the hospital industry's financial savings associated with the utilization of each type of fuel cell technology in 2001. Installed costs and O&M have been provided by fuel cell manufacturers. It is on this basis that saved costs are calculated. Exhibit 7-8 presents the financial savings estimated for 2010. Cost savings are only provided for employment size classes that have a market potential for utilizing fuel cells (see Section 7.3, Fuel Cell Market Potential). Financial savings presented in parentheses indicate negative savings which means that the current fuel cell electricity cost exceeds the average annual electricity cost incurred within the hospital industry sector from local electricity suppliers.

**EXHIBIT 7-7: FINANCIAL SAVINGS FROM FUEL CELL IMPLEMENTATION IN THE HOSPITAL INDUSTRY (2001)**

| EMPLOYMENT SIZE CLASS | NUMBER OF ESTABLISHMENTS | COST OF ELECTRICITY (¢/KWH) | PAFC (¢/KWH) | PEMFC (¢/KWH) | SOFC (¢/KWH) | MCFC (¢/KWH) |
|---|---|---|---|---|---|---|
| 20–99 | 768 | 6.3 | N/A | N/A | (12) | N/A |
| 100–499 | 3,040 | 6.3 | (3) | (12) | (12) | (9) |
| 500+ | 2,816 | 6.3 | (3) | (12) | (12) | (9) |

N/A: No fuel cell is compatible with that particular employee range.

The data indicate that a direct implementation of fuel cells in the hospital industry sector in 2001 is not economically profitable. However, projections provided from manufacturers, as well as energy projections provided by the EIA, provide a more positive economic outlook for implementing fuel cells in the hospital industry sector for the year 2010.

In 2010, PAFC technology is the most economically feasible choice for the hospital industry with a cost savings of 0.1 ¢/kWh. However, due to the hospital industry's need for both electric and high temperature thermal energy, the SOFC and MCFC technology are more promising because they are high temperature fuel cells in spite of their slight economic disadvantage. PAFC technology is estimated to provide a cost savings of 0.1 ¢/kWh in 2010;

equivalent to an annual saving of $14.4 million /year for all hospitals with approximately 100 to 499 employees and $31 million /year for all hospitals with 500 or more employees.

**EXHIBIT 7-8: FINANCIAL SAVINGS FROM FUEL CELL IMPLEMENTATION IN THE HOSPITAL INDUSTRY (2010)**

| EMPLOYMENT SIZE CLASS | NUMBER OF ESTABLISHMENTS | PURCHASED ELECTRICITY (¢/KWH) | PAFC (¢/KWH) | PEMFC (¢/KWH) | SOFC (¢/KWH) | MCFC (¢/KWH) |
|---|---|---|---|---|---|---|
| 20–99 | 848 | 6.3 | 0.1 | (0.2) | (0.3) | N/A |
| 100–499 | 3,358 | 6.3 | 0.1 | (0.2) | (0.3) | (0.3) |
| 500+ | 3,111 | 6.3 | 0.1 | (0.2) | (0.3) | (0.3) |

N/A: Not Applicable — No fuel cell is compatible with that particular employee range.

### 7.5.2 Economic Factors on Market Penetration

The economic feasibility of fuel cells entering the hospital industry sector has been organized into the economic factors presented below. These factors were identified earlier in Chapter 3.0.

- Acquisition Costs
- Annual O&M Costs
- Other Indirect Costs
- Lead Time
- Service Life
- Annual Revenue from the Sale of Electricity
- Possible Energy Tax Credits/Rebates/Grants
- Emissions Credits

Each economic factor is described below with respect to the hospital industry sector. The relative importance of each factor to the hospital industry sector is denoted by the number of " ì " to right of the heading. One star (minimum) indicates low importance and three stars (maximum) indicates high importance.

#### 7.5.2.1 Acquisition Costs ì ì ì

For fuel cells to be used at health care facilities, the unit cost of power they produce must be comparable or less than the cost of power available through other means (i.e., purchased grid power). As a component of the unit cost per kWh produced, acquisition costs will be an important factor to the acceptance of the technology.

#### 7.5.2.2 Annual Operation and Maintenance (O&M) Costs ì ì ì

As a component of the unit cost per kWh produced, annual operation and maintenance costs will be an important factor in the acceptance of the technology in health care facilities.

#### 7.5.2.3 Other Indirect Costs i i i

As a component of the unit cost per kWh produced, other indirect costs of fuel cells will be an important factor in the acceptance of the technology.

#### 7.5.2.4 Lead Time i

Use of fuel cell technology would be a long term capital improvement that would be permanent in nature. Thus, long lead times would not be a significant factor in the acceptance of the technology.

#### 7.5.2.5 Service Life i

The health care industry generally expects electronic equipment to have a useful service life of 5 to 10 years, and other equipment (i.e., vacuum cleaners, washing machines, etc) to have a service life of 20 to 30 years. Thus, fuel cells are expected to have a service life similar to other health care activities. Service life is not expected to be a significant factor in the acceptance of the technology.

#### 7.5.2.6 Annual Revenue from the Sale of Electricity i

Most electricity produced by fuel cells at hospitals would be consumed onsite. Thus, revenue for the sale of electricity may be an important consideration for individual hospitals, but will probably not be an important factor for the health care industry as a whole.

#### 7.5.2.7 Possible Energy Tax Credits/Rebates/Grants i i

Because the decision to employ fuel cell technology at health care facilities will be primarily economically driven, tax credits/rebates/grants could be an important stimulus to developing the acceptance of the technology.

#### 7.5.2.8 Emissions Credits i

Since a program for emissions credits for employing fuel cell technology does not currently exist, this is not an important factor in the acceptance of the technology.

### 7.6 Environmental Assessment

The purpose of the environmental assessment is to determine the potential reduction in air emissions ($CO_2$, $SO_2$ and $NO_x$) and the conservation of natural resources associated with utilizing fuel cells as the primary energy source in the hospital industry sector as opposed to energy from traditional U.S. energy plants. A qualitative assessment of the environmental factors that influence the marketability of fuel cells is also included as part of the environmental assessment. In general, fuel cells have a large environmental advantage over traditional sources of energy (as represented by the national average for the U.S. energy grid). However, a detailed life-cycle assessment would be necessary to compare the actual environmental benefits of fuel cell technologies to the current U.S. energy grid.

The results of the environmental assessment is divided into three parts: 1) pollution avoided ($CO_2$, $SO_2$ and $NO_x$); 2) natural resources conserved; and 3) the environmental factors on market penetration. Each section is described below.

### 7.6.1 Pollution Avoided ($CO_2$, $SO_2$, $NO_x$)

The avoided pollution is determined by subtracting the pollution emitted by fuel cells if they were used as a power source instead of the power grid from the pollution emitted by the power grid based on the electricity consumption of the hospitals industry sector. The calculation is as follows:

Pollution Avoided = (Pollution Emitted by the Grid) - (Pollution Emitted by Fuel Cells)

The utilization of fuel cells in general reduces emissions as illustrated by the performance specifications of the different types of fuel cells. Fuel cells produce low levels of emissions per kWh of electricity compared to the emissions produced by the power grid per kWh of electricity. The “pollution avoided,” as mentioned above, is calculated to determine the environmental advantages of fuel cells as an alternative source of primary power. Exhibit 7-9 illustrates the potential magnitude of pollution avoided if fuel cells were fully implemented (100% of the market potential) within the hospital industry sector in the years 2001 and 2010. The percentage of pollution avoided when using fuel cells instead of the main grid is also provided for 2001 and 2010 in Exhibit 7-9. Manufacturer’s data suggests that for all four types of fuel cells, the amount of pollution generated during operation is virtually the same. This is due to similar types of chemical reactions occurring in each case.

**EXHIBIT 7-9: POTENTIAL POLLUTION AVOIDED IF FUEL CELLS OBTAINED 100% OF THE MARKET POTENTIAL IN THE HOSPITAL INDUSTRY SECTOR IN 2001 AND 2010**

| Employment Size Class | 2001 | | 2010 | |
|---|---|---|---|---|
| | Pollution Avoided (million lbs.) | Percent Reduction (%) | Pollution Avoided (million lbs.) | Percent Reduction (%) |
| 20–99 | 268 | 28 | 297 | 28 |
| 100–499 | 5,312 | 28 | 5,868 | 28 |
| 500+ | 11,481 | 28 | 12,678 | 28 |

Based on the findings in Exhibit 7-9, the use of fuel cells will result in a reduction of 28% of pollution with respect to air emissions. A comprehensive analysis of competing fuel cell technologies to traditional energy sources (U.S. energy grid) would be necessary to improve the accuracy of the rough-order-of-magnitude assessment conducted.

### 7.6.2 Fuel Conserved by Using Fuel Cells in 2001 and 2010

In addition to reducing air emissions, the use of fuel cells reduces the amount of fossil fuels used to generate electricity. Of the total electricity consumed in the U. S in 1999, coal generated 51% of electricity, oil generated 3.2%, gas generated 15.3%, nuclear generated 19.7%, hydroelectric sources generated 8.3%, and other sources generated 2.4% (EIA). The proportions are very similar for 1998, and it is reasonable to assume that the same proportions apply to the year 2001. It is possible to calculate the quantities of fossil fuel (coal, oil and natural gas) that would not be consumed if fuel cells were to be used instead as a primary source of power. Exhibits 7-10 and 7-11 illustrate the potential magnitude of "displaced fuel," or natural resources conserved if fuel cells were fully implemented (100% of the market potential) within the hospital industry sector in the years 2001 and 2010. These exhibits also account for the natural gas being used as the fuel source for the fuel cells.

**EXHIBIT 7-10: NATURAL RESOURCES CONSERVED IN 2001**

| | | | NATURAL RESOURCES CONSERVED | |
|---|---|---|---|---|
| EMPLOYMENT SIZE CLASS | NUMBER OF ESTABLISHMENTS | ELECTRICITY CONSUMPTION (MWH/YR) | COAL (MILLION LBS.) | OIL (THOUSAND GAL.) |
| 20–99 | 768 | 660,787 | 301 | 2,075 |
| 100–499 | 3,040 | 13,078,080 | 5,955 | 41,067 |
| 500+ | 2,816 | 28,267,008 | 13,054 | 90,028 |

Natural gas being used by the fuel cells is not taken into account in this table.

**EXHIBIT 7-11: NATURAL RESOURCES CONSERVED IN 2010**

| | | | NATURAL RESOURCES CONSERVED | |
|---|---|---|---|---|
| EMPLOYMENT SIZE CLASS | NUMBER OF ESTABLISHMENTS | ELECTRICITY CONSUMPTION (MWH/YR) | COAL (MILLION LBS.) | OIL (THOUSAND GAL.) |
| 20–99 | 848 | 729,920 | 322 | 2,292 |
| 100–499 | 3,358 | 14,446,337 | 6,369 | 45,364 |
| 500+ | 3,111 | 31,224,362 | 13,961 | 99,447 |

Natural gas being used by the fuel cells is not taken into account in this table.

Exhibit 7-12 shows the amount of natural gas consumed when fuel cells are implemented in the Hospital industry sector, the amount of natural gas displaced by not using current energy sources, and the resulting net increase in natural gas consumption.

**EXHIBIT 7-12: ACTUAL FUEL CONSUMED AND CONSERVED WHEN USING FUEL CELLS IN 2010**

| SCHOOL SIZE CLASS (EMPLOYEES) | AVERAGE POWER DEMAND (kW) | NATURAL GAS CONSUMED (MILLION cu. ft.) | NATURAL GAS DISPLACED (MILLION cu. ft.) | NET NATURAL GAS (MILLION cu. ft.) |
|---|---|---|---|---|
| 20-99 | 98 | 6,263 | 661 | (5,603) |
| 100-499 | 491 | 124,218 | 13,073 | (111,144) |
| 500+ | 1,146 | 268,562 | 28,256 | (240,306) |

### 7.6.3 Environmental Factors for Market Penetration

The key environmental factors associated with fuel cells entering the hospital industry sector have been organized into the following factors:

- Air Emissions
- Wastewater Production
- Solid Waste Production
- Resource Usage
- Life-Cycle Related Benefits

Each environmental factor is described below with respect to the hospital industry sector. The relative importance of each factor to the hospital industry sector is denoted by the number of " i " to right of the heading. One star (minimum) indicates low importance and three stars (maximum) indicates high importance.

#### 7.6.3.1 Air Emissions i i

Except for emissions due to onsite incineration of medical and other waste, air emissions in hospital facilities are almost exclusively accounted for by the emissions produced by the power grid during electricity production. Using fuel cell technology can show a positive reduction in associated air emissions. This is an important factor in evaluating potential fuel cell use at hospitals.

#### 7.6.3.2 Wastewater Production i

Wastewater generation is not expected to be an important factor in the acceptance of the technology in the hospital industry sector since fuel cells produce little/no measurable wastewater.

#### 7.6.3.3 Solid Waste Production i

Solid waste generation from PAFC fuel cells generally consists of non-hazardous materials (i.e., filter cartridges); and spent catalysts which can be reclaimed and recycled. Solid waste generation for other types of fuel cells are expected to be similar and comparable on a per unit basis to the waste generated by the power grid. Therefore, solid waste generation is not expected to be an important factor in the acceptance of fuel cell technology.

#### 7.6.3.4 Resource Usage i i

The principal resource required is a gas hydrocarbon fuel (e.g., natural gas, hydrogen, methane, etc.) as a feedstock to operate a fuel cell. Natural gas is commonly available in all hospitals that are located in areas equipped with natural gas service. Utilizing a local service provider to obtain the required natural gas feedstock for operating the fuel cells is the most practical approach for the hospital industry sector. Therefore, based on the need for gas hydrocarbon fuel to operate the fuel cell, resource usage is anticipated to be an important factor in the acceptance of the technology.

#### 7.6.3.5 Life-Cycle Related Benefits i i

Fuel cell technology is considered to be almost pollution free during its operation (minimal $CO_2$, $SO_2$, $NO_x$, cooling/rinse water, and negligible solid waste). In terms of downstream end-of-life impacts, most manufacturers are reporting that they expect the majority of the fuel cell components to be recyclable (95% by weight according to IFC). Most of the remaining 5% are anticipated to be land filled with less than 1% being hazardous waste (heavy metal wastes from the cell and/or ancillary fluids). Since very few fuel cell systems have been decommissioned to date, these end-of-life estimates need to be revised as substantiating data become available. In terms of upstream impacts, the life cycle impacts are anticipated to be those common to manufacturing/assembly activities (e.g., structural frame, plumbing, and insulation), including solvents and chemicals from metal processing, paints and coatings, and other assembly/production by-products. Thus, compared to electricity produced by the power grid, life-cycle related benefits are anticipated to be relatively important factors in the acceptance of fuel cell technology.

## 7.7 Institutional Considerations

Institutional considerations affecting the marketability of fuel cells in the hospital industry sector has been organized into the factors presented below. These factors were identified earlier in Chapter 3.0.

- Regulatory Barriers
- Market/Customer Acceptance
- Staff Experience/Training Required

Each institutional factor is described below with respect to the hospital industry sector. The relative importance of each factor to the hospital industry sector is denoted by the number of " ¡ " to the right of the heading. One star (minimum) indicates low importance and three stars (maximum) indicates high importance.

### 7.7.1 Regulatory Barriers ¡

Because fuel cells are an emerging technology, regulatory standards and codes have not yet been developed. As fuel cells gain greater acceptance in this, and other industries, appropriate codes and standards will likely emerge. Thus, regulatory barriers are not anticipated to be an important factor in the acceptance of the technology.

### 7.7.2 Market/Customer Acceptance ¡ ¡

The market/customer acceptance relates to how receptive and motivated a customer is to use a fuel cell system in place of its current sources of power. This particular factor includes reviewing what the customer has invested in providing and maintaining the current power sources (which is linked to the economic factors), the willingness of a customer to utilize cutting-edge innovative technology, and for this particular sector, how the public will value and balance other benefit factors (such as environmental factors) in deciding whether to use fuel cell technology.

### 7.7.3 Staff Experience/Training Required ¡

While the fuel cells themselves may be relatively simple to operate, the gas conditioning processes needed for both PAFC and PEMFC technologies may require operation and maintenance skills that may be found in health care facilities where sensitive and complex equipment is used on a daily basis. Thus, staff expertise and the training needed will not be a significant factor in the acceptance of fuel cell technology in the hospital industry sector.

## 7.8 Summary of Fuel Cell Opportunities in the Hospital Industry Sector

The hospital industry sector is a solid candidate for accepting and implementing fuel cell technology in the future. The hospital industry can benefit directly from increased reliability (greater than six 9's reliability, 99.9999%, with an effective energy management strategy) and reduced energy costs through onsite generation of electric and thermal power.

Exhibit 7-13 summarizes the relative importance of the technical, cost, environmental, and acceptance/institutional factors that will influence the marketability of fuel cells in the hospital industry sector. The relative importance of each factor to the hospital industry sector is denoted by the number of " i " to right of the heading. One star (minimum) indicates low importance and three stars (maximum) indicates high importance.

With respect to technical capabilities, all four types of fuel cell technologies have market potential matching the projected operating ranges available in 2010 to the energy demands of the industry. PAFC, PEMFC, and SOFC have the greatest potential market size comprising 7,317 hospital establishments (95% of the hospital market) while the MCFC potential market is slightly reduced due to the operating range of the technology (6,469). However, both MCFCs and SOFCs have a competitive advantage over the other types of technology due to their ability to produce both electricity and high temperature thermal energy better matching the energy needs of the hospital market.

While there are significant technical advantages for fuel cells in the hospital industry, fuel cells also have several significant technical challenges to overcome in the next several years of development before becoming widely accepted within the industry. The first challenge is also a predicted strength: reliability. Fuel cells are considered an emerging technology in the field of distributed generation sources and therefore, this technology has very minimal historical data to prove it is a reliable energy source. The second challenge is complexity. Operating and maintaining a fuel cell is not as simple as maintaining an oil or diesel fired boiler. A trained technician will be required to maintain and repair (if necessary) the fuel cell. Due to the complexity of the technology and lack

**Exhibit 7-13: Summary of Factors Influencing Marketability of Fuel Cells in the Hospital Industry Sector**

| Technical Factors | |
|---|---|
| Technology maturity | i i i |
| Physical space requirements | i i i |
| Infrastructure requirements | i |
| Start-up time | i |
| Co-generation options | i i |
| Fuel efficiency | i |
| Output reliability/consistency | i i i |
| Fuel flexibility | i |
| **Economic Factors** | |
| Acquisition costs (purchase and installation) | i i i |
| Annual operation and maintenance costs | i i i |
| Lead Time | i |
| Other annual indirect costs (e.g., liability, environmental) | i i i |
| Service life | i |
| Annual revenue from sale of output | i |
| Annual business energy tax credits/rebates (Federal, State, local) | i i |
| Emissions credits | i |
| **Environmental Factors** | |
| Air emissions | i i |
| Wastewater releases | i |
| Solid waste (non-hazardous and hazardous) | i |
| Resource usage (water, fuel feedstock) | i i |
| Life-Cycle related benefits | i i |
| **Institutional Factors** | |
| Regulatory barriers | i |
| Management/customer acceptance | i i |
| Staff expertise/training required | i |

i i i - 3 Stars denote factors critical to marketability in the hospital sector.

of experienced service technicians in the local market, fuel cell leasing or long-term service contract options are expected in the hospital industry until these technological challenges are overcome with time, reduced complexity, and confidence in the market.

With respect to cost feasibility, PAFC technology is the most economically feasible choice for the hospital industry with a cost savings of 0.1 ¢/kWh; however, due to the hospital industry's need for both electric and high temperature thermal energy, the SOFC and MCFC technology are most likely to be implemented. PAFC implementation would be equivalent to an annual savings of $14.4 million/year for hospitals with approximately 100-499 employees and $31 million/year for hospitals with 500 or more employees. Extrapolating the cost savings for PAFC for the estimated market potential of 7,317 establishments within the hospital industry sector, the potential annual savings in 2010 would be $46.4 million.

The financial savings afforded by fuel cells is impressive for the hospital industry; however, decision-makers will most likely have a difficult time justifying the capital project unless existing on-site power supplies (backup power and thermal energy sources) need significant repair or replacement. Therefore, external assistance in the form of Federal or state grants, tax credits, or other incentives will be necessary for existing hospitals to consider upgrading their energy management systems. Construction of new hospital establishments are more likely to consider investing in fuel cell technologies, but the anticipated market growth over the next 10 years is minimal, about 1% annually. External factors, such as increased environmental regulations limiting air releases of greenhouse gases and deregulation of electricity in the U.S. causing decreased reliability in energy from local suppliers in the short-term, may overcome the financial risks of investing in fuel cell technology in the future. A second challenge facing the cost feasibility of fuel cell technology in the year 2010 is its ability to meet the (fuel cell) industry's predicted reductions in investment and operating and maintenance costs in the future compared to today's investment costs.

The environmental benefits of fuel cells are significant in comparison to air emissions associated with traditional energy sources (i.e., U.S. energy grid). A reduction in air emissions of 28% or 19 billion pounds is expected. However, the implementation of fuel cells in the hospital industry alone will not be great enough to actually realize the environmental benefits unless other industries in the same region adopt fuel cells or other distributed generation technologies to offset the Region's increase in demand for electricity. Unlike other industries, which are centralized in specific regions across the U.S., hospitals are evenly distributed with respect to population density. Therefore, the combined effects of implementing fuel cells will be difficult to realize due to the regional nature of the U.S. energy supply system. Efforts to decentralize the U.S. energy supply through deregulation, and creating greater coast-to-coast commerce may help the hospital industry realize the actual environmental benefits received from implementing fuel cells.

These challenges should in no way discount the fact that fuel cells are an environmentally-friendly energy source and wide-scale adoption will have a significant effect in reducing the release of greenhouse gases while preserving natural resources (i.e., coal, oil, natural gas, etc.). Fuel cells are one of several distributed generation technologies that will play a key role in meeting the country's future increases in energy demand by reducing the need for traditional, less environmentally-friendly, energy plants from being brought into operation or constructed. A primary goal identified by the 2001 National Energy Policy is to utilize renewable and alternative energy sources such as fuel cells to meet the Nation's future energy demands through cleaner and more efficient technologies.

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# 8.0 Telecommunications Industry Sector Analysis

As a result of the industry prioritization (see Chapter 4.0), the telecommunications industry sector ranked in the First (top) tier with a fuel cell market potential of 20,108 establishments estimated for the year 2010 or 22% of the total market based on the fuel cell compatibility of their average power demand.

The purpose of this chapter is to provide a detailed analysis of the potential market for fuel cells within the telecommunications industry sector. The results of the detailed analysis have been divided into the following eight areas:

- Definition of the Telecommunications Industry Sector — Section 8.1
- Industry Sector Profile for 2010 — Section 8.2
- Fuel Cell Market Potential — Section 8.3
- Technical Assessment — Section 8.4
- Cost Assessment — Section 8.5
- Environmental Assessment — Section 8.6
- Institutional Considerations — Section 8.7
- Summary of Fuel Cell Opportunities in the Telecommunications Industry Sector — Section 8.8

Each area is described in detail below.

## 8.1 Definition of Telecommunications Industry Sector

The telecommunications industry sector is comprised of establishments primarily engaged in operating, maintaining or providing access to facilities for the transmission of voice, data, text, and full motion picture video between network termination points and telecommunications reselling. Transmission facilities may be based on a single technology or a combination of technologies. As defined by the NAICS, this industry includes the following sub-sectors:

- 51331 Wired Telecommunications Carriers
- 513310 Wired Telecommunications Carriers
- 51332 Wireless Telecommunications Carriers (except Satellite)
- 513321 Paging
- 513322 Cellular and Other Wireless Telecommunications
- 51333 Telecommunications Resellers
- 513330 Telecommunications Resellers
- 51334 Satellite Telecommunications
- 513340 Satellite Telecommunications

## 8.2 Industry Sector Profile for 2010

The results of the year 2010 industry sector profile of the telecommunication industry were estimated by scaling historical (1998 and 1999, respectively) data using an estimated growth rate for the industry while holding other factors constant. Understanding the foundation of the industry sector profile is important to understanding the uncertainty in the results and properly interpreting and communicating the results in a transparent manner. The methodology used to generate the telecommunications industry sector profile for 2010 is explained below.

### 8.2.1 Methodology

Publicly available data characterizing the telecommunications industry sector (number of employees per establishment) in 1999 was combined with detailed energy statistics (amount of energy consumed per employee) in 1995 to estimate the electrical and thermal demand of small, medium, and large telecommunications facilities in the United States (U.S.). The amount of energy consumed per employee in telecommunications was assumed to be constant between 1995 and 1998 in correlating the data to determine the average power demand, total energy consumption (relative to the U.S. electrical grid), and the pounds of air emissions released from U.S. power plants (based on 1998 E-Grid data) as a result of the amount of energy consumed by small, medium, and large telecommunications support facilities in 1999.

The results were scaled from the present to 2010 by assuming a 9.5% annual growth in the telecommunications industry sector. The growth rate was determined by analyzing the U.S. Census Bureau's County Business Patterns (CBP) data for the growth rate in the number of establishments in the telecommunications industry sector from 1998 to 1999. The number of establishments (small, medium, and large) was increased annually by the growth rate while the following variables were assumed to remain constant:

- Amount of energy consumed per telecommunications employee
- Distribution of small, medium, and large telecommunication facilities within the industry sector
- Emissions profile from the U.S. electricity grid was assumed to remain constant per kilowatt (kW) of power consumed.

### 8.2.2 Size of Industry Sector

The geographic distribution of telecommunications support facilities shows a concentration of these facilities along the east coast, in Texas and in California. Matching the concentration of these facilities and the distribution of electricity costs throughout the U.S. will allow for a more targeted analysis of fuel cell opportunities. Exhibit 8-1 shows the distribution of telecommunications support facilities across the U.S.

EXHIBIT 8-1: GEOGRAPHICAL DISTRIBUTION OF TELECOMMUNICATIONS ESTABLISHMENTS ACROSS THE UNITED STATES IN 2010

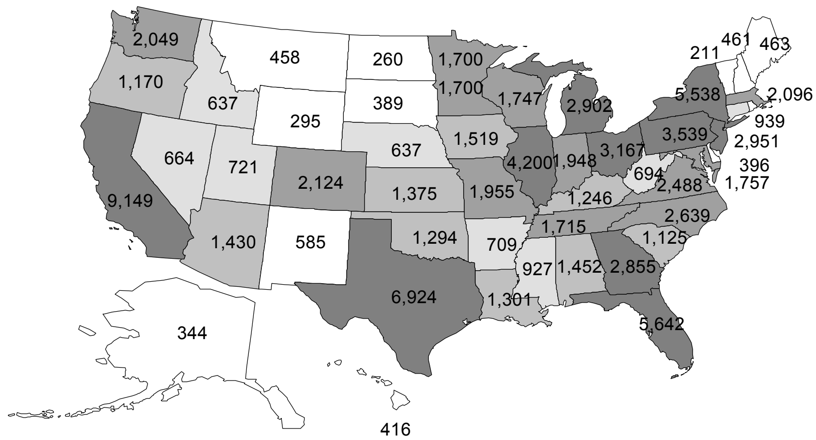



Exhibit 8-2 presents a list of the ten states with the highest number of telecommunications support facilities.

**EXHIBIT 8-2: NUMBER OF TELECOMMUNICATION ESTABLISHMENTS FOR THE TOP TEN STATES IN 2010**

| STATE | NUMBER OF ESTABLISHMENTS[A] | PERCENT (%) OF TOTAL ESTABLISHMENTS[B] |
|---|---|---|
| California | 9,149 | 10.0 |
| Texas | 6,924 | 7.6 |
| Florida | 5,642 | 6.2 |
| New York | 5,538 | 6.0 |
| Illinois | 4,200 | 4.6 |
| Pennsylvania | 3,539 | 3.9 |
| Ohio | 3,167 | 3.5 |
| New Jersey | 2,951 | 3.2 |
| Michigan | 2,902 | 3.2 |
| Georgia | 2,855 | 3.1 |
| *Subtotal* [C] | 46,867 | 51.2 |
| Other [D] | 44,675 | 48.8 |
| *Total* [E] | 91,542 | 100 |

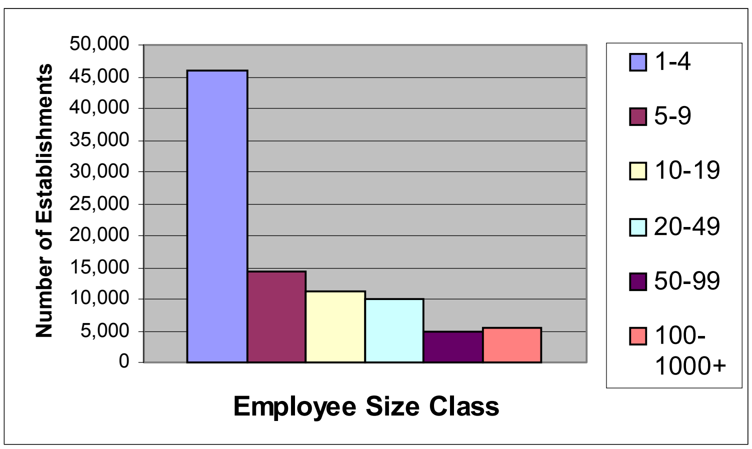
A Represents the number of telecommunications support facilities in each state.
B Equals the number of facilities in a state divided by the Total and then multiplied by 100.
C Equals the sum of facilities in the 10 states with the highest number of facilities.
D Equals the sum of facilities in the remaining 40 states.
E Equals the sum of facilities in the entire United States.

As far as relevant trends characterizing the telecommunications support industry sector, one critical factor is the rapid growth of facilities with its collateral increase in electricity and heat consumption, in associated polluting emissions from energy generation and increased workforce.

In 1998 and 1999, the telecommunications support industry (NAICS code 5133), showed an increase in the number of facilities nationwide of 9.5%. The closest equivalent noted in the Standard Industry Classification (SIC) system (tracking earlier years) was SIC Code 48 which showed an average increase of 3% over five years (1993 to 1997) but encompassed different subsections of the telecommunications industry. For lack of better data extending over a significant period of time and considering the thriving telecommunications industry, it is reasonable to assume a growth of 9.5% over the next ten years. The growth in the number of establishments is assumed to spur energy consumption and increase pollutant emissions in the same proportions.

Exhibit 8-3 shows a distribution of the sizes of the telecommunications facilities in the U.S. The size of the facility is represented by the range of employees working there.

**EXHIBIT 8-3: DISTRIBUTION OF ESTABLISHMENTS BY EMPLOYMENT SIZE CLASS FOR THE TELECOMMUNICATIONS INDUSTRY IN 2010**




Establishments within the telecommunications industry sector can roughly be divided into six employment size classes: 1 to 4, 5 to 9, 10 to 19, 20 to 49, 50 to 99, and 100 to 1000+ employees respectively. Exhibit 8-3 illustrates the distribution of establishments relative to employee size. As illustrated in the exhibit, the telecommunications industry sector consists primarily of small to mid-sized establishments approximately 66% having between 1 and 9 employees and 22% having greater than 20 employees.

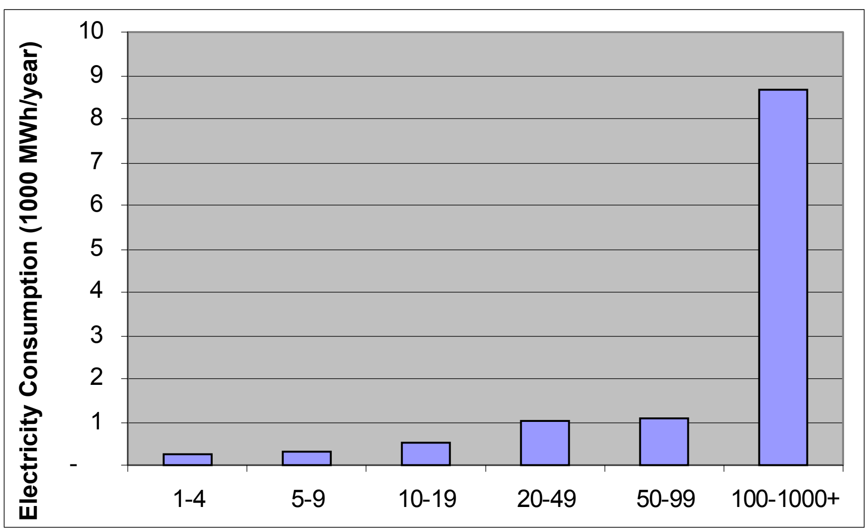
### 8.2.3 Annual Energy Consumption and Related Utility Plant Air Emissions

Energy usage in the telecommunications support industry is derived primarily from the DOE's Energy Information Administration (EIA). A breakdown of the energy consumption of commercial buildings classified in the Commercial Building Electricity Consumption Survey (CBECS) shows that for an office, the consumption of electricity is about 7.3 MWh per employee, and the thermal consumption is equal to half the electrical consumption.

From an energy consumption standpoint, the type of activity performed in a telecommunications support facility resembles that of an average commercial office, hence total energy consumption can be derived. It is assumed that these telecommunications support facilities are offices.

Exhibit 8-4 illustrates the electricity needs by facility size. Size is expressed in terms of the number of employees per facility.

**EXHIBIT 8-4: DISTRIBUTION OF ELECTRICITY CONSUMPTION PER EMPLOYEE RANGE IN 2010**




The telecommunications facilities that have between 1 and 99 employees consume under 7.8 GWh/year of electricity while those that employ 100 to1,000 or more consume over 20 GWh/year of electricity.

The telecommunications support industry sector encompasses a wide array of facilities. One way to classify these facilities is to sub-divide them based upon numbers of employees.

Smaller facilities will require less energy than larger ones, thus impacting the ability of fuel cells to be used as a potential alternative to the traditional power sources especially the main power grid. Exhibit 8-5 shows a detailed analysis of electricity and heat consumption along with the emissions produced by the power grid during electricity production. These emissions are calculated assuming a national average (E-Grid database, EIA, 1998) of emissions due to purchased power grid.

The average power demand, listed in the exhibit, is calculated assuming that the electricity is being consumed at a rate of 24 hours a day, 365 days a year, or 8,760 hours per year. It is a measure of the instantaneous power need of a given facility. The average power demand is the primary metric to which the power output of a fuel cell is compared in order to evaluate its suitability for use. All numbers are given per year.

**EXHIBIT 8-5: TELECOMMUNICATIONS INDUSTRY ENERGY CONSUMPTION AND RELATED UTILITY PLANT AIR EMISSIONS FOR 2010**

| RANGE OF EMPLOYEES | 1–4 | 5–9 | 10–19 | 20–49 | 50–99 | 100–1,000+ | TOTAL |
|---|---|---|---|---|---|---|---|
| **Number of Establishments** | 46,083 | 14,196 | 11,153 | 9,924 | 4,844 | 5,340 | 91,542 |
| **Total Electricity Consumption (MWh)** | 672,817 | 725,439 | 1,221,306 | 2,535,682 | 2,652,358 | 21,440,461 | 29,248,063 |
| **Average Power Demand (kW)** | 2 | 6 | 13 | 29 | 63 | 458 | N/A |
| **Total Thermal Consumption (MWh)** | 336,409 | 362,720 | 610,653 | 1,267,841 | 1,326,179 | 10,720,231 | 14,624,032 |
| **Total $CO_2$ Emissions (million lbs.)** | 956 | 1,030 | 1,735 | 3,602 | 3,767 | 30,453 | 41,542 |
| **Total $SO_2$ Emissions (million lbs.)** | 5 | 5 | 9 | 19 | 20 | 160 | 219 |
| **Total $NO_x$ Emissions (million lbs.)** | 2 | 3 | 4 | 9 | 9 | 76 | 104 |
| **Total Emissions (million lbs.)** | 963 | 1,038 | 1,748 | 3,630 | 3,797 | 30,689 | 41,865 |

* Not applicable. Average Power demand is specific to a single facility.
Note: Average power demand is based on an annual usage of 8,760 hours per year (100%). Power demand represents the average over a one-year period of time; therefore, it does not reflect the actual power demands of a specific establishment or industry (i.e., high demand and low demand).

Emissions generated during electricity production in the U.S. were calculated using a national average of 1420.33 lbs./MWh of $CO_2$, 7.5 lbs./MWh of $SO_2$ and 3.55 lbs./MWh of $NO_x$ as derived from EPA's E-Grid database using power plant emissions factors for the National energy grid. Over the next ten years, the National average for air emissions released from the U.S. production of electricity (electricity grid) will change due to advanced technologies for traditional energy sources and the market penetration of new and distributed generation energy sources. Modeling and prediction of potential changes to future environmental burdens from U.S. energy sources was beyond the scope of this effort; therefore, a level of uncertainty is accepted in the predicted mass of pollution created or avoided.

### 8.3 Fuel Cell Market Potential

The fuel cell market potential is determined by matching the average power demand of each employment size class (i.e., 1 to 4, 5 to 9, 10 to 19, 20 to 49, 50 to 99, and 100 to 1,000+) from the industry sector profile (see Section 8.2.3) with the estimated compatibility range of each type of fuel cell (see Chapter 3.0 for an overview of each type of fuel cell). The average power demand is a measure of the instantaneous power need of a given facility. Exhibit 8-6 highlights the potential market size for different fuel cell technologies in 2010.

All four types of fuel cell technologies have market potential in the telecommunications industry matching the projected operating ranges available in 2010 to the energy demands of the industry. Exhibit 8-6 highlights the potential market size for different fuel cell technologies in 2010 with Y (Yes) indicating where a particular fuel cell technology is expected to be marketable and N (No) indicating where there is no potential market. PAFC and PEMFC have the greatest potential market size comprising 20,108 telecommunications establishments (22% of the telecommunications market). SOFC technology has a market potential of 10,184 establishments while the MCFC potential market is significantly reduced (5,340 establishments) due to the operating range of the technology.

**EXHIBIT 8-6: FUEL CELL MARKET POTENTIAL FOR 2010**

| Employment Size Class | Number of Establishments | Average Power Demand (kW) | Fuel Cell Technology & Projected Operating Range for 2010 [A] | | | |
|---|---|---|---|---|---|---|
| | | | PAFC (50 – 250 kW) | PEMFC (50–- 250 kW) | SOFC (50 kW–- 5 MW) | MCFC (250 kW – 5 MW) |
| 1–4 | 46,083 | 2 | N | N | N | N |
| 5–9 | 14,196 | 6 | N | N | N | N |
| 10–19 | 11,153 | 13 | N | N | N | N |
| 20–49 | 9,924 | 29 | Y | Y | N | N |
| 50– 99 | 4,844 | 63 | Y | Y | Y | N |
| 100–1,000 + | 5,340 | 458 | Y | Y | Y | Y |
| | | Potential Market Size: | 20,108 | 20,108 | 10,184 | 5,340 |

[A] In determining fuel cell size compatibility, the projected operating capabilities for 2010 were expanded by reducing the lower range by 50% and increasing the upper range by 500% to account for the ability to operate the fuel cell at 50% capacity or operate 5 fuel cell systems in parallel.

## 8.4 Technical Assessment

The technical feasibility of fuel cells entering the telecommunications industry sector has been organized into the technical factors presented below. These factors were identified earlier in Chapter 3.0.

- Technology Maturity
- Physical Space Requirements
- Infrastructure Requirements
- Start-up time
- Co-generation Potential
- Fuel Efficiency
- Output Reliability/Consistency
- Fuel Flexibility

Each technical factor is described below with respect to the telecommunications industry sector. The relative importance of each factor to the telecommunications industry sector is denoted by the number of " ı " to right of the heading. One star (minimum) indicates low importance and three stars (maximum) indicates high importance.

### 8.4.1 Technology Maturity ı ı ı

Most telecommunications facilities perceive power generation to be outside the sphere of their current mission. The maturity of the technology is expected to be a significant factor affecting fuel cell technology acceptance by this industry.

### 8.4.2 Physical Space Requirements ı ı ı

This is not an easy problem to solve as most telecommunications support facilities operate in relatively small spaces. In typical telecommunications support facilities, PAFC or PEMFC fuel cells could be located nearby, externally, in the basement or in another area of the building.

### 8.4.3 Infrastructure Requirements ı ı

Acceptance by telecommunications support facilities of fuel cell technology and related costs are likely to be dependent upon the added costs associated with the transport and storage of natural gas, methane or hydrogen. The needed infrastructure for this delivery is likely to be a relatively significant factor in the acceptance of the technology.

### 8.4.4 Start-up Time ı

Fuel cells installed for base-load power at telecommunications support facilities would have to operate continuously in order to minimize the capital cost per unit of power generated.

Continuous operation would make start-up time relatively insignificant in the acceptance of the technology in telecommunications support facilities. Start-up time would be more critical for backup systems.

### 8.4.5 Co-generation Potential i

Telecommunications support facilities, much like offices, only need an external source of heat in order to control internal temperature. The ability of fuel cells to use the heat generated in their operation to return heat to the facility can be appreciable in that it will eliminate the need for an alternative source of heat. However, the potential for co-generation is not a crucial factor in the acceptance of the technology.

### 8.4.6 Fuel Efficiency i

Since telecommunications facilities do not generate a fuel source onsite, fuel must instead be provided. Thus, fuel efficiency is not an important factor in the acceptance of the technology.

### 8.4.7 Output Reliability/Consistency i i i

The reliability of the fuel cell units will be a critical factor not only in determining the cost of the power generated, but also in determining the viability of fuel cell technology in telecommunications support facilities. Sensitive equipment at telecommunications support facilities cannot sustain power variations. Loss of computing capability due to unreliable power would result in severe economic concerns for telecommunications facilities. Thus, output reliability/consistency is considered an important factor in the acceptance of the technology.

### 8.4.8 Fuel Flexibility i

Fuel flexibility is not relevant to the telecommunications support sector since fuel is not generated onsite.

## 8.5 Cost Assessment

The purpose of the cost assessment is to determine the financial viability of fuel cells being accepted within the telecommunications industry sector. In general, fuel cells will be accepted if the cost of operating and maintaining a fuel cell is equal to or less than the cost associated with purchasing energy from a local supplier; *if*, the fuel cell can improve the reliability (power quality) of electricity for the telecommunications support facilities.

The cost assessment is divided into two parts: 1) the estimated cost savings of purchasing and operating a fuel cell in the telecommunications industry sector in the year 2010; and 2) a qualitative assessment of the relative importance of various economic factors to the telecommunications industry sector.

### 8.5.1 Estimated Cost Savings

Information was collected from fuel cell manufacturers to estimate the cost of electricity produced by fuel cells. The cost of electricity includes the installed cost (over a 10 year service life), the fuel purchase cost, and the operation and maintenance costs (O&M). Exhibit 8-7 summarizes the cost of fuel cells for the year 2001 and Exhibit 8-8 summarizes the fuel cell cost predictions for the year 2010. Unlike previous sections in this Chapter, fuel cell and/or industry market data representing the year 2001 is presented in conjunction with 2010 predictions due to the significant level of uncertainty in the 2010 cost estimates. The increased level of uncertainty in the cost predictions are based on the lack of maturity and history of fuel cells. The consumption of fuel is estimated at 1,900 $ft^3$/hour of methane as reported by the Energy Research and Development Center (US Army Corps of Engineers) during the EPA Fuel Cell Workshop held in Cincinnati Ohio, June 26–27, 2001.

The total cost, as expressed in the rightmost column of both Exhibit 8-7 and Exhibit 8-8, is the sum of the installation cost over 10 years, the operation and maintenance (O&M) cost and the fuel cost.

**EXHIBIT 8-7: ESTIMATES OF OVERALL ANNUAL FUEL CELL COSTS (2001)**

| | AVERAGE INSTALLED COST ($/kW) | AVERAGE INSTALLED COST (¢/kWh) | INSTALLATION COST OVER 10 YEARS (¢/kWh) | O&M COST (¢/kWh) | FUEL COST (¢/kWh) | TOTAL COST (¢/kWh) |
|---|---|---|---|---|---|---|
| **PAFC** | 2,500 | 28.54 | 2.85 | 1.75 | 5.08 | 9.68 |
| **PEMFC** | 10,000 | 114.16 | 11.42 | 1.75 | 5.08 | 18.25 |
| **SOFC** | 10,000 | 114.16 | 11.42 | 1.5 | 5.08 | 18.00 |
| **MCFC** | 8,000 | 91.32 | 9.13 | 1.5 | 5.08 | 15.71 |

Note: Total cost is the sum of the installed cost over 10 years, O&M costs and fuel costs.

The cost projections for 2010, provided by manufacturers indicate a sharp decline in installed costs, O&M costs, and fuel costs for each fuel cell technology. The combination of all these declines results in an overall decrease in total costs for all fuel cells between 2001 and 2010 of approximately 55 % in average per fuel cell.

**EXHIBIT 8-8: ESTIMATES OF OVERALL ANNUAL FUEL CELL COSTS (2010)**

| | AVERAGE INSTALLED COST ($/kW) | AVERAGE INSTALLED COST (¢/kWh) | INSTALLATION COST OVER 10 YEARS (¢/kWh) | O&M COST (¢/kWh) | FUEL COST (¢/kWh) | TOTAL COST (¢/kWh) |
|---|---|---|---|---|---|---|
| **PAFC** | 875 | 9.99 | 1.00 | 1.00 | 4.16 | 6.16 |
| **PEMFC** | 1,200 | 13.70 | 1.37 | 1.00 | 4.16 | 6.53 |
| **SOFC** | 1,250 | 14.27 | 1.43 | 1.00 | 4.16 | 6.59 |
| **MCFC** | 1,250 | 14.27 | 1.43 | 1.00 | 4.16 | 6.59 |

Note: Total cost is the sum of the installed cost over 10 years, O&M costs and fuel costs.

The estimated costs saved by utilizing fuel cell technology is derived by subtracting fuel cell costs from electricity prices when provided by a local electricity supplier. The average annual electricity cost, for the telecommunications industry, is 7.1 ¢/kW (EIA). Exhibit 8-9 presents for the telecommunications industry the cost savings associated with utilizing each type of fuel cell technology in 2001 and Exhibit 8-10 presents the cost savings estimated for 2010. Cost savings are only provided for employment size classes that have a market potential for utilizing fuel cells (see Section 8.3, Fuel Cell Market Potential). Cost savings presented in parentheses indicate negative savings which means that the current fuel cell electricity cost exceeds the average annual electricity cost incurred within the telecommunications industry sector from local electricity suppliers.

**EXHIBIT 8-9: FINANCIAL SAVINGS FROM FUEL CELL IMPLEMENTATION IN THE TELECOMMUNICATIONS INDUSTRY (2001)**

| EMPLOYMENT SIZE CLASS | NUMBER OF ESTABLISHMENTS | COST OF ELECTRICITY (¢/kWh) | PAFC (¢/kWh) | PEMFC (¢/kWh) | SOFC (¢/kWh) | MCFC (¢/kWh) |
|---|---|---|---|---|---|---|
| 50-99 | 1,955 | 7.1 | N/A | N/A | (11) | N/A |
| 100–1,000+ | 2,155 | 7.1 | (3) | (11) | (11) | (9) |

N/A: Not Applicable - No fuel cell is compatible with that particular employee range.

A direct implementation of fuel cells in the telecommunications industry sector in 2001 is not economically profitable. Projections provided from manufacturers, as well as energy projections provided by the Energy Information Administration (EIA), provide a more positive economic outlook for implementing fuel cells in the telecommunications industry sector for the year 2010.

**EXHIBIT 8-10: FINANCIAL SAVINGS FROM FUEL CELL IMPLEMENTATION IN THE TELECOMMUNICATIONS INDUSTRY (2010)**

| EMPLOYMENT SIZE CLASS | NUMBER OF ESTABLISHMENTS | COST OF ELECTRICITY (¢/kWh) | PAFC (¢/kWh) | PEMFC (¢/kWh) | SOFC (¢/kWh) | MCFC (¢/kWh) |
|---|---|---|---|---|---|---|
| 20-49 | 9,924 | 7.1 | 0.9 | 0.6 | N/A | N/A |
| 50–99 | 4,844 | 7.1 | 0.9 | 0.6 | 0.5 | N/A |
| 100–1,000+ | 5,340 | 7.1 | 0.9 | 0.6 | 0.5 | 0.5 |

N/A: Not Applicable - No fuel cell is compatible with that particular employee range.

PAFC technology is the most economically feasible choice for the telecommunications industry with a cost savings in 2010 of up to 0.9 ¢/kWh. This would be equivalent to an annual savings of $36,135/year for a telecommunications facility with more than 100 employees. Extrapolating the cost savings for a PAFC for the estimated market potential of 20,108 establishments within the telecommunications industry sector, the potential annual savings for the telecommunications industry in 2010 would be $239 million/year. In 2010, all four fuel cell technologies are likely to be implemented.

### 8.5.2 Economic Factors on Market Penetration

The economic feasibility of fuel cells entering the telecommunications industry sector has been organized into the economic factors presented below. These factors were identified earlier in Chapter 3.0.

- Acquisition Costs
- Annual O&M Costs
- Other Indirect Costs
- Lead Time
- Electricity
- Service Life
- Annual Revenue from the Sale of
- Possible Energy Tax Credits/Rebates /Grants
- Emissions Credits

Each economic factor is described below with respect to the telecommunications industry sector. The relative importance of each factor to the telecommunications industry sector is denoted by the number of " ì " to right of the heading. One star (minimum) indicates low importance and three stars (maximum) indicates high importance.

#### 8.5.2.1 Acquisition Costs ì ì ì

For fuel cells to be used at telecommunications support facilities, the unit cost of power they produce must be comparable or less than the cost of power available through other means (i.e., purchased grid power). As a component of the unit cost per kWh produced, acquisition costs will be an important factor in the acceptance of the technology.

#### 8.5.2.2 Annual Operation and Maintenance (O&M) Costs i i i

As a component of the unit cost per kWh produced, annual O&M costs will be an important factor in the acceptance of the technology.

#### 8.5.2.3 Other Indirect Costs i i i

As a component of the unit cost per kWh produced, other indirect costs of fuel cells will be an important factor in the acceptance of the technology.

#### 8.5.2.4 Lead Time i

Use of fuel cell technology would be a long term capital improvement that would be permanent in nature. Thus, long lead times would not be a significant factor in the acceptance of the technology in telecommunications support facilities.

#### 8.5.2.5 Service Life i

The telecommunications support industry generally expects electronic equipment to have a useful service life of five to ten years, and other equipment (i.e., housekeeping equipment, etc.) to have a service life of 20 to 30 years. Thus, fuel cells are expected to have a service life similar to other telecommunications support activities. Service life is not expected to be a significant factor in the acceptance of the technology.

#### 8.5.2.6 Annual Revenue from the Sale of Electricity i

Electricity produced by fuel cells at telecommunications support facilities would be consumed onsite. Thus, revenue for the sale of electricity while possibly an important consideration for a few facilities, will probably not be an important factor for the industry as a whole.

#### 8.5.2.7 Possible Energy Tax Credits/Rebates/Grants i i

Because the decision to employ fuel cell technology at telecommunications support facilities will be primarily economically driven, tax credits/rebates/grants could be an important stimulus to developing the acceptance of the technology.

#### 8.5.2.8 Emissions Credits

i

Since a program for emissions credits for employing fuel cell technology does not currently exist, this is not an important factor in the acceptance of the technology.

## 8.6 Environmental Assessment

The purpose of the environmental assessment is to determine the potential reduction in air emissions ($CO_2$, $SO_2$ and $NO_x$) and the conservation of natural resources associated with utilizing fuel cells as the primary energy source in the telecommunications industry sector as opposed to energy from traditional U.S. energy plants. A qualitative assessment of the environmental factors that influence the marketability of fuel cells is also included as part of the environmental assessment. In general, fuel cells have a large environmental advantage over traditional sources of energy (as represented by the national average for the U.S. energy grid). However, a detailed life-cycle assessment would be necessary to compare the actual environmental benefits of fuel cell technologies to the current U.S. energy grid.

The results of the environmental assessment are divided into three parts: 1) pollution avoided ($CO_2$, $NO_x$, $SO_2$); 2) natural resources conserved; and 3) the environmental factors on market penetrations. Each section is described below.

### 8.6.1 Pollution Avoided ($CO_2$, $SO_2$, NOx)

The avoided pollution is determined by subtracting the pollution emitted by fuel cells if they were used as a power source instead of the power grid from the pollution emitted by the power grid based on the electricity consumption of the telecommunications support industry sector. The calculation is as follows:

Pollution Avoided = (Pollution Emitted by the Grid) - (Pollution Emitted by Fuel Cells)

The utilization of fuel cells in general reduces emissions as illustrated by the performance specifications of the different types of fuel cells. Fuel cells produce low levels of emissions per kWh of electricity compared to the emissions produced by the power grid per kWh of electricity. The “pollution avoided,” as mentioned above, is calculated to determine the environmental advantages of fuel cells as an alternative primary source of power. Exhibit 8-11 illustrates the potential magnitude of pollution avoided if fuel cells were fully implemented (100% of the market potential) within the telecommunications industry sector in the years 2001 and 2010. The percentage of pollution avoided when using fuel cells instead of the main grid is also provided for 2001 and 2010 in Exhibit 8-11.

**EXHIBIT 8-11: POTENTIAL POLLUTION AVOIDED IF FUEL CELLS OBTAINED 100% OF THE MARKET POTENTIAL IN THE TELECOMMUNICATIONS INDUSTRY SECTOR IN 2001 AND 2010**

| EMPLOYMENT SIZE CLASS | 2001 | | 2010 | |
|---|---|---|---|---|
| | POLLUTION AVOIDED (MILLION lbs.) | PERCENT REDUCTION (%) | POLLUTION AVOIDED (MILLION lbs.) | PERCENT REDUCTION (%) |
| 20–49 | N/A | N/A | 1,030 | 28 |
| 50–99 | 435 | 28 | 1,077 | 28 |
| 100–1,000+ | 3,541 | 28 | 8,708 | 28 |

N/A: Not Applicable - No fuel cell is compatible with that particular employee range.

Based on the findings in Exhibit 8-11, a reduction of air emissions of 28 percent is expected if fuel cells are utilized. A comprehensive analysis of competing fuel cell technologies to traditional energy sources (U.S. energy grid) would be necessary to improve the accuracy of the rough-order-of-magnitude assessment conducted.

### 8.6.2 Calculate Fuel Conserved by Using Fuel Cells in 2001 and 2010

In addition to reducing air emissions, the use of fuel cells reduces the amount of fossil fuels used to generate electricity. In 1999, coal generated 51% of electricity, oil generated 3.2%, natural gas generated 15.3%, nuclear generated 19.7%, hydroelectric sources generated 8.3%, and other sources generated 2.4% (EIA) of the total electricity consumed in the U.S. The proportions are very similar for 1998, and it is reasonable to assume that the same proportions apply to the year 2001. It is possible to calculate the quantities coal, oil and natural gas that would not be consumed if fuel cells were to be used instead as a primary source of power. Exhibits 8-12 and 8-13 illustrate the potential magnitude of "displaced fuel," or natural resources conserved if fuel cells were fully implemented (100% of the market potential) within the telecommunications industry sector in the years 2001 and 2010.

**EXHIBIT 8-12: NATURAL RESOURCES CONSERVED IN 2001**

| EMPLOYMENT SIZE CLASS | NUMBER OF ESTABLISHMENTS | ELECTRICITY CONSUMPTION (MWh/yr) | NATURAL RESOURCES CONSERVED | |
|---|---|---|---|---|
| | | | COAL (MILLION lbs.) | OIL (THOUSAND gal.) |
| 50–99 | 1,955 | 1,070,363 | 488 | 3,362 |
| 100–1,000+ | 2,155 | 8,652,325 | 3,940 | 27,176 |

**EXHIBIT 8-13: NATURAL RESOURCES CONSERVED IN 2010**

| EMPLOYMENT SIZE CLASS | NUMBER OF ESTABLISHMENTS | ELECTRICITY CONSUMPTION (MWh/yr) | NATURAL RESOURCES CONSERVED | |
|---|---|---|---|---|
| | | | COAL (MILLION lbs.) | OIL (THOUSAND gal.) |
| 20–49 | 9,924 | 2,535,682 | 1,118 | 7,964 |
| 50–99 | 4,844 | 2,652,358 | 1,170 | 8,330 |
| 100–1,000+ | 5,340 | 21,440,461 | 9,454 | 67,343 |

Exhibit 8-14 shows the amount of natural gas consumed when fuel cells are implemented in the telecommunications industry, the amount of natural gas displaced by not using current energy sources, and the resulting net increase in natural gas consumption.

**EXHIBIT 8-14: ACTUAL FUEL CONSUMED AND CONSERVED WHEN USING FUEL CELLS IN 2010**

| EMPLOYEE RANGE | AVERAGE POWER DEMAND (kW) | NATURAL GAS CONSUMED (MILLION cu. ft.) | NATURAL GAS DISPLACED (MILLION cu. ft.) | NET NATURAL GAS (MILLION cu. ft.) |
|---|---|---|---|---|
| 20–49 | 29 | 9,666 | 2,295 | (7,371) |
| 50–99 | 63 | 10,250 | 2,400 | (7,850) |
| 100–1,000+ | 458 | 82,137 | 19,402 | (62,735) |

### 8.6.3 Environmental Factors for Market Penetration

The key environmental factors associated with fuel cells entering the telecommunications industry sector have been organized into the factors presented below. These factors were identified earlier in Chapter 3.0.

- Air Emissions
- Wastewater Production
- Solid Waste Production
- Resource Usage
- Life-Cycle Related Benefits

Each environmental factor is qualitatively described below with respect to the telecommunications industry sector. The relative importance of each factor to the telecommunications industry sector is denoted by the number of “ i ” to right of the heading. One star (minimum) indicates low importance and three stars (maximum) indicates high importance.

#### 8.6.3.1 Air Emissions i i

Air emissions due to telecommunications support facilities are almost exclusively from the emissions produced by the power grid during electricity production. Since using fuel cell technology can show a positive reduction in associated air emissions, this is an important factor in evaluating potential fuel cell use at telecommunications support facilities.

#### 8.6.3.2 Wastewater Production i

No significant quantities of wastewater emissions are expected to be generated by fuel cells. Thus wastewater generation is not expected to be an important factor in the acceptance of the technology.

#### 8.6.3.3 Solid Waste Production i

Solid waste generation from fuel cells generally consists of non-hazardous materials (i.e., filter cartridges), and spent catalysts, which can be reclaimed and recycled. Solid waste generation for other types of fuel cells is expected to be similar and is comparable on a per unit basis to the waste generated by the power grid. Thus, solid waste generation is not expected to be an important factor in the acceptance of the technology.

#### 8.6.3.4 Resource Usage i i

The principal resource required as a feedstock for the fuel cells is a gas hydrocarbon fuel. Such a feedstock will have to be purchased as it cannot possibly be produced onsite. Thus, because of the added costs associated with purchase of feedstock, resource usage is anticipated to be a relatively important factor in the acceptance of the technology.

#### 8.6.3.5 Life-Cycle Related Benefits i i

Fuel cell technology is considered to be almost pollution free during its operation (minimal $CO_2$, $SO_2$ and $NO_x$, cooling/rinse water, and negligible solid waste). In terms of downstream end-of-life impacts, most manufacturers are reporting that they expect the majority of the fuel cell components to be recyclable (95% by weight according to IFC). Most of the remaining 5% are anticipated to be landfilled with less than 1% being hazardous waste (heavy metal wastes from the cell and/or ancillary fluids). Since very few fuel cell systems have been decommissioned to date, these end-of-life estimates need to be revised as substantiating data become available. In terms of upstream impacts, the life cycle impacts are anticipated to be those common to manufacturing/assembly activities (e.g., structural frame, plumbing, and insulation) including solvents and chemicals from metal processing, paints and coatings, and associated other assembly/production by-products. Thus, compared to electricity produced by the power grid, life-cycle related benefits are anticipated to be relatively important factors in the acceptance of the technology.

## 8.7 Institutional Considerations

Institutional considerations affecting the marketability of fuel cells in the telecommunications industry sector have been organized into the factors presented below. These factors were identified earlier in Chapter 3.0.

- Regulatory Barriers
- Market/Customer Acceptance
- Staff Experience/Training Required

Each institutional factor is described below with respect to the telecommunications industry sector. The relative importance of each factor to the telecommunications industry sector is denoted by the number of " i " to right of the heading. One star (minimum) indicates low importance and three stars (maximum) indicates high importance.

### 8.7.1 Regulatory Barriers i

Because fuel cells are an emerging technology, regulatory standards and codes have not yet been developed. As fuel cells gain greater acceptance in this, and other industries, appropriate codes and standards will likely emerge. Thus, regulatory barriers are not anticipated to be an important factor in the acceptance of the technology.

### 8.7.2 Market/Customer Acceptance i i

The market/customer acceptance relates to how receptive and motivated a customer is to use a fuel cell in place of its current sources of power. This particular factor includes reviewing what the customer has invested in providing and maintaining the current power sources (which is linked to the economic factors), the willingness of a customer to utilize cutting-edge innovative technology; and for this particular sector, how the public will value and balance other benefit factors (such as the environmental) in deciding whether to use fuel cell technology.

### 8.7.3 Staff Experience/Training Required i i

While the fuel cells themselves may be relatively simple to operate, the gas conditioning processes needed for both PAFC and PEMFC technologies may require O&M skills that may or may not be found in telecommunications support facilities where sensitive and complex equipment is used on a daily basis. Thus, staff expertise and the training needed could be a significant factor in the acceptance of fuel cell technology.

## 8.8 Summary of Fuel Cell Opportunities in the Telecommunications Industry Sector

Fuel cells are one of several distributed generation technologies that will play a key role in meeting the country's increasing energy demands. The introduction and emergence of fuel cell technology in the telecommunications industry as an alternative to the electric power grid is growing in acceptance because of the promising environmental and economic benefits offered in the present but particularly in the future. Fuel cells are an environmentally-friendly energy source and wide-scale adoption will have a significant affect in reducing the releases of greenhouse gases while preserving natural resources (i.e., coal, oil, natural gas, etc.).

The Chief Operating Officer of Nuvera Fuel Cells stated that "[t]oday's supply of electricity generation is insufficient to give the surge in economic growth and demand for power. There is a growing need, especially in the telecommunications industry to develop distributed generation sources that are clean, modular, and robust alternatives to the electric grid. Fuel cells offer an attractive energy source in this power range, and the telecom industry provides a promising early market to demonstrate their reliability and effectiveness."

To this end, as part of a multi-phased fuel cell demonstration project, Nuvera Fuel Cells partnered with Verizon (the newly formed telecommunications company resulting from the merger of Bell Atlantic and GTE) to develop, test, and evaluate fuel cell powered demonstration units in the 5kW range. The project was designed to develop greater insight and understanding about the power generation equipment for the telecommunications industry.

**Exhibit 8-15: Summary of Factors Influencing Marketability of Fuel Cells in the Telecommunications Support Industry Sector**

| | |
|---|---|
| **Technical Factors** | |
| Technology maturity | i i i |
| Physical space requirements | i i i |
| Infrastructure requirements | i i |
| Start-up time | i |
| Co-generation options | i |
| Fuel efficiency | i |
| Output reliability/consistency | i i i |
| Fuel flexibility | i |
| **Economic Factors** | |
| Acquisition costs (purchase and installation) | i i i |
| Annual operation and maintenance costs | i i i |
| Lead Time | i |
| Other annual indirect costs (e.g., liability, environmental) | i i i |
| Service life | i |
| Annual revenue from sale of output | i |
| Annual business energy tax credits/rebates (Federal, State, local) | i i |
| Emissions credits | i |
| **Environmental Factors** | |
| Air emissions | i i |
| Wastewater releases | i |
| Solid waste (non-hazardous and hazardous) | i |
| Resource usage (water, fuel feedstock) | i i |
| Life-Cycle related benefits | i i |
| **Institutional Factors** | |
| Regulatory barriers | i |
| Management/customer acceptance | i i |
| Staff expertise/training required | i i |

i i i - 3 Stars denote factors critical to marketability in the telecommunications support sector.

Under the second phase, Nuvera and Verizon hope to demonstrate a fuel cell technology at a community based Verizon equipment hut or remote site. The last phase will involve field testing a customized telecom-specific power generator. The partners hope to adapt the fuel cell technology for use as primary or backup power for telecom switch nodes, cell towers, and other electronic systems.

Several companies are developing fuel cell technology with an eye towards the telecommunications industry sector. For example, DCH Technology has developed a fuel cell that stands approximately 2 feet high and has a 2.5 square foot foot print. In a press release dated June 27, 2001, DCH indicated its intention to target its high-power portable fuel cell for use in the telecommunications sector. http://www.dcht.com/press_release/press_release.esp

In a press release dated October 1998, Hpower won a $6.4 million contract from NIST to jointly develop a propane-fueled, Fuel Cell Power System for the telecommunications industry sector. It will be designed to operate on propane and designed to replace batteries for telecommunications applications; for example, those involved with transmitting data from remote monitoring stations.

Although quite promising, the current cost of fuel cell technology are very high which has prevented its penetration of the market. The relative importance of cost and other factors (e.g., technical, environmental and acceptance factors) that will influence the marketability of fuel cells in the telecommunications support industry sector is presented in Exhibit 8-15. The relative importance of each factor to the telecommunications industry sector is denoted by the number of "M" to right of the heading. One star (minimum) indicates low importance and three stars (maximum) indicates high importance.

The results of this study indicate that in 2010, the PAFC, PEMFC, SOFC and MCFC technologies can be utilized within the telecommunications industry sector. However, the fuel cells with the greatest market potential in the industry are the PAFC and PEMFC comprising a potential market size of 20,108 telecommunications establishments (22% of the telecommunications market). The potential market size for the SOFC and MCFC technologies are 10,184 and 5,340 respectively. The number of establishments is significantly reduced due to the increased operating range of the technology. In short, those establishments with the largest number of employees are most likely to benefit from the fuel cell technology.

The maturity of the fuel cell technology is expected to be a significant factor affecting fuel cell technology acceptance by this industry. The physical size of the technology is also a concern to the acceptance of the technology since most telecommunications support facilities operate in relatively small spaces. In typical telecommunications support facilities, PAFC or PEMFC fuel cells could be located nearby, externally, in the basement or in another area of the building.

Additionally, telecommunications support facilities primarily require electrical power. Most applications also require premium power and instantaneous/reliable backup power systems in order to avoid information losses and/or processing delays. The economic stake is such that they also necessitate strong and reliable backup systems with fast start-up time. The reliability of the fuel cell units will be a critical factor not only in determining the cost of the power generated, but also in determining the viability of fuel cell technology in telecommunications support facilities. Sensitive equipment at telecommunications support facilities cannot sustain power variations. Loss of computing capability due to unreliable power would result in severe economic concerns for telecommunications facilities. Thus, output reliability/consistency is considered an important factor in the acceptance of the technology.

For fuel cells to be used at telecommunications support facilities, the unit cost of power they produce must be comparable or less than the cost of power available through other means (i.e., purchased grid power). As a component of the unit cost per kWh produced, acquisition costs, annual O&M costs, and other indirect costs will be important factors in the acceptance of the technology in telecommunications support facilities. In addition, other indirect costs of fuel cells will be an important factor in the acceptance of the technology. In terms of financial savings, utilizing manufacturers projections for 2010, a sharp decline in installed costs O&M costs and fuel costs for each fuel cell technology is projected resulting in an overall decrease in fuel cell costs from 2001 of 55% per average fuel cell. In 2010 an estimated financial savings of $239 million and $159.7 million is expected if PAFC and PEMFC technologies are implemented in the telecommunications industry.

Air emissions due to telecommunications support facilities are almost exclusively from the emissions produced by the power grid during electricity production. Since using fuel cell technology can show a positive reduction in associated air emissions ($CO_2$, $SO_2$ and $NO_x$), this is an important factor in evaluating potential fuel cell use at telecommunications support facilities. In 2010, telecommunications establishments utilizing fuel cell technologies are expected to generate a total of 25,732 million lbs./yr. of energy-related emissions. This represents a reduction of 28%.

A gas hydrocarbon fuel is typically used as a feedstock for fuel cells which will have to be purchased. Because of the added costs associated with purchase of feedstock, resource usage is expected to be a relatively important factor in the acceptance of the technology in telecommunications support facilities. However, data collected for this study indicate that the conservation of natural resources resulting from the use of fuel cells far outweighs the associated cost of the purchasing fuel for the use in the fuel cell. For example, in the telecommunications industry, the use of fuel cells in 2010 will result in the conservation of 7,307 million lbs. of coal and 2,677 thousand gallons of oil.

Another concern regarding the acceptance of fuel cells in the telecommunications industry is staff expertise and training needed to ensure the efficient operation of the fuel cell.

The fuel cells themselves are relatively simple to operate; however, the gas conditioning processes needed for both PAFC and PEMFC technologies may require O&M skills that may or may not be found in telecommunications support facilities where sensitive and complex equipment is used on a daily basis. Consequently, there may be some costs associated with hiring and training staff to operate the PAFC and PEMFC technologies.

In spite of the various technical, economic and environmental factors discussed, the telecommunications industry is a growing industry involved in computers, communications technologies and even the Internet. These and other telecommunications applications require an economical and reliable power source as an alternative to the electrical power grid. The fuel cell technologies identified in this report may offer the source of high quality, reliable power to support the energy needs of the industry sector while offering significant environmental benefits.

# 9.0 Wastewater Treatment Industry Sector Analysis

Based on the industry sector prioritization applied in Chapter 4.0, the wastewater treatment plant (WWTP) industry sector ranked in the second tier. However, it was elevated to Tier 1 in part due to its high priority interest to the U.S. Environmental Protection Agency, a sponsor of this research. The WWTP industry sector has a fuel cell market potential of 4,209 establishments estimated for the year 2010 or 100% of the total market based on the fuel cell compatibility of their average power demand.

This chapter provides a detailed analysis of the potential market for fuel cells in the year 2010 within the WWTP industry sector. The results of the detailed analysis have been divided into the following eight areas:

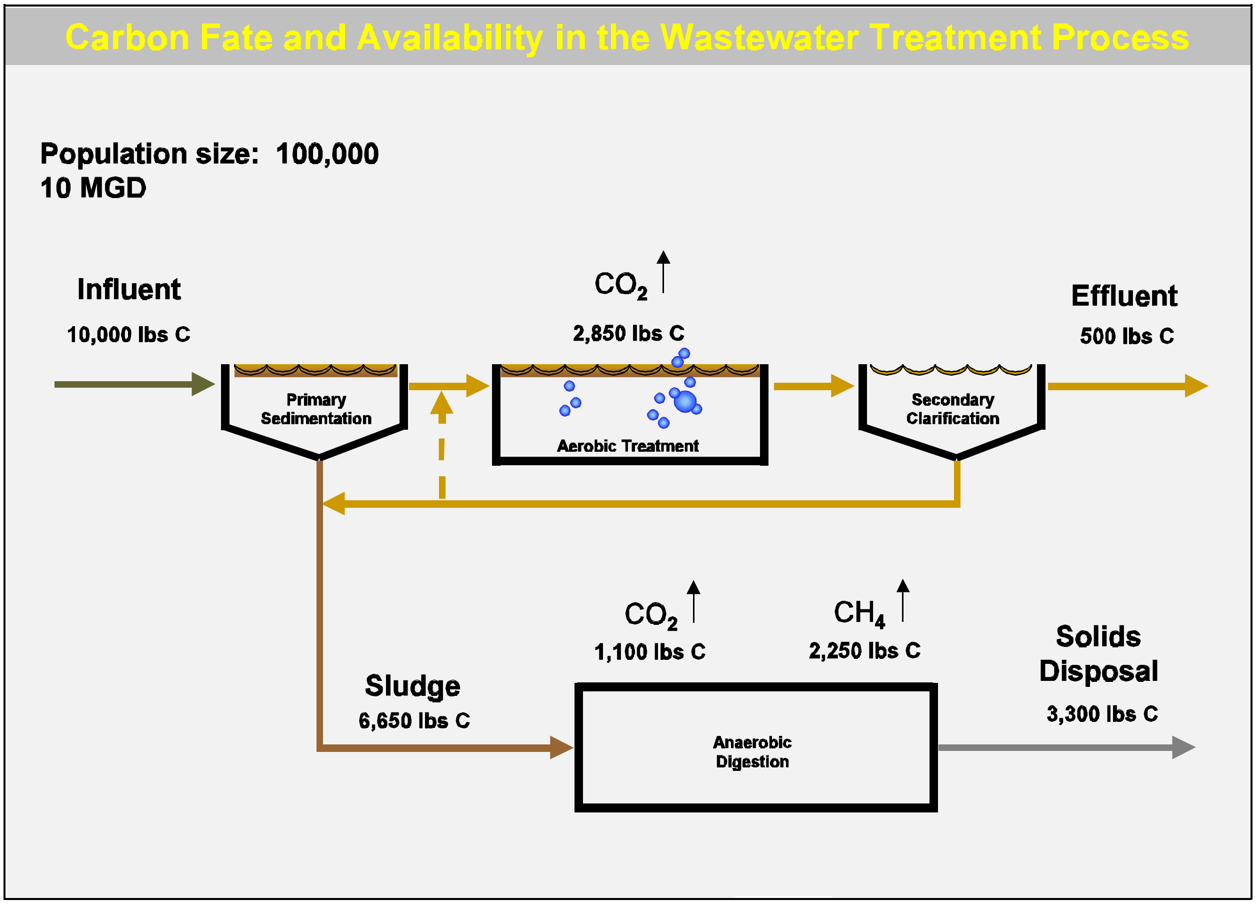
- Definition of the WWTP Industry Sector — Section 9.1
- Industry Sector Profile — Section 9.2
- Fuel Cell Market Potential — Section 9.3
- Technical Assessment — Section 9.4
- Cost Assessment — Section 9.5
- Environmental Assessment — Section 9.6
- Institutional Considerations — Section 9.7
- Summary of Fuel Cell Opportunities in the WWTP Industry Sector — Section 9.8

Each area is described in detail below.

## 9.1 Definition of Wastewater Treatment Plant Sector

The wastewater treatment plant industry includes those facilities, typically owned and operated by some form of local government, that treat wastewater collected from a combination of residential, commercial, and industrial sources. The NAICS Code for these facilities is 22132. The solids handling and treatment processes are where the opportunities for fuel cells lie. Wastewater treatment produces significant quantities of biological sludge which must be treated and disposed. Sludge processing typically involves several steps including stabilization which is intended to reduce both the volume of sludge and the level of pathogens it contains. The stabilization of wastewater is accomplished either through aerobic or anaerobic digestion. Exhibit 9-1 illustrates the wastewater treatment process and is further explained in the text box that follows.

EXHIBIT 9-1: CARBONATE FATE AND AVAILABILITY IN THE WASTEWATER TREATMENT PROCESS



***Wastewater Treatment Process***

After preliminary treatment to remove grit and debris, wastewater is sent to primary sedimentation tanks where organic solids are separated by gravity. These solids are removed from the bottom of the tanks and sent to solids processing. The clarified wastewater, called primary effluent, then goes to aeration tanks where it is mixed with air and a culture of micro-organisms referred to as mixed liquor. In the presence of dissolved oxygen, these organisms adsorb and degrade organic constituents of the wastewater converting them to carbon dioxide and new micro-organism cells. The mixed liquor wastewater combination then flows to secondary clarifiers where the micro-organisms are allowed to settle to the bottom and the clarified water exits for discharge. The settled solids are returned to the aeration tank to treat additional wastewater. Since the treatment process produces additional microbial cells, a portion of the mixed liquor must be removed each day to maintain a constant population of organisms in the aeration tank. This is accomplished by diverting a small portion of the secondary clarifier return flow, called waste solids, to the solids processing system.

Anaerobic digestion is one of several processes that can be used to process solids received from the primary sedimentation process, and waste solids from the aerobic treatment process. Anaerobic digestion is the biological degradation of complex organic substances in the absence of free oxygen. During these reactions, energy is released and much of the organic matter is converted to methane, carbon dioxide, and water. Since little carbon and energy remain available to sustain further biological activity, the remaining solids are rendered stable.

Anaerobic digestion involves two phases. In the first phase of digestion, facultative bacteria convert complex organic substances to short-chain organic acids. These volatile organic acids tend to reduce the pH although alkaline buffering materials are also produced. Organic matter is converted to a form suitable for breakdown by the second group of bacteria. In the second phase, strictly anaerobic bacteria (called methanogens) convert the volatile acids to methane ($CH_4$), carbon dioxide ($CO_2$), and other trace gases.

## 9.2 Industry Sector Profile

The results of the year 2010 industry sector profile of the WWTP industry were estimated by scaling historical data using an estimated growth rate for the industry while holding other factors constant. The foundation of the industry sector profile is important to understanding the uncertainty in the results and to properly interpreting and communicating the results in a transparent manner. The following explains the methodology used to generate the WWTP industry sector profile for 2010.

### 9.2.1 Methodology

Publicly available data characterizing the WWTP industry sector in 1996 (million gallons per day, or MGD) was combined with detailed energy statistics (amount of energy consumed per MGD) in 1995 to estimate the electrical and thermal demand of small, medium, and large WWTP's in the United States (U.S.). The amount of energy consumed in a WWTP was correlated with data to determine the average power demand, total energy consumption (relative to the U.S. electrical grid), and the pounds of air emissions released from U.S. power plants (based on 1998 E-Grid data) as a result of the amount of energy consumed by small, medium, and large WWTPs.

To assess opportunities in 2010, a 2% annual growth was assumed in the WWTP industry sector. This number was based on the best professional judgement of a WWTP sector expert. The number of establishments (small, medium, and large) was increased annually by the 2% growth rate, while the following variables were assumed to remain constant:

- Amount of energy consumed per WWTP size
- Distribution of small, medium, and large WWTP facilities within the industry sector
- Emissions profile from the U.S. electricity grid (assumed to remain constant per kilowatt (kW) of power consumed).

### 9.2.2 Size of Industry Sector (Distribution of WWTPs Using Anaerobic Digestion and Digester Gas)

The potential market for fuel cell technologies is represented by those wastewater treatment plants which have anaerobic digestion processes. The plants that emit anaerobic digester gases (ADG) are prime candidates for fuel cell implementation because the ADG generated can be used as a fuel source for the fuel cells, thus decreasing or possibly eliminating the need for outside purchase of natural gas. According to the 1996 Clean Water Needs Survey[1], of the 16,024 facilities in the survey, there are a total of 3,452[2] wastewater treatment plants (WWTPs) that use anaerobic digestion to treat sewage. Of those plants, 266 plants currently utilize the digester gas produced from the anaerobic digestion.

Exhibit 9-2 displays the geographic distribution of the WWTPs in the U.S. that have anaerobic digestion processes. As indicated on the map and shown in Exhibit 9-3, ten states account for over 54 % of the anaerobic digestion plants with the State of California accounting for just under 10 %. A note of interest is that with the exception of California and Texas, all of the other states are in the Great Lakes Region.

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[1]The EPA Office of Wastewater Management conducts the Clean Water Needs Survey (CWNS) on a periodic basis. The CWNS, a joint effort between States and EPA, has information on publicly-owned wastewater collection and treatment facilities, facilities for control of sanitary sewer overflows (SSOs), combined sewer overflows (CSOs), storm water control activities, nonpoint sources, and programs designed to protect the nation's estuaries.

[2] As stated, 266 facilities reportedly use digester gas. Eight of those facilities failed to report that they use anaerobic digestion to treat sewage; therefore, 8 facilities were added to the total number of facilities that reported the use of anaerobic digestion to treat sewage.

**EXHIBIT 9-2: GEOGRAPHIC DISTRIBUTION OF WWTPS USING ANAEROBIC DIGESTION**

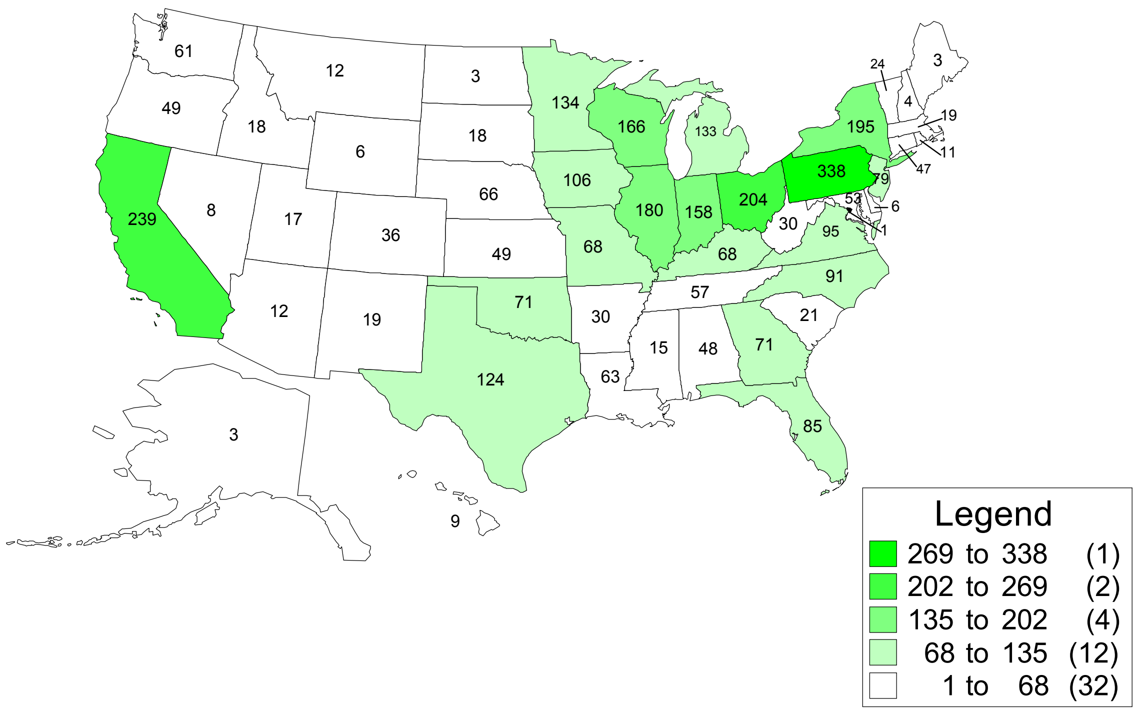



**EXHIBIT 9-3: STATES WITH LARGEST NUMBER OF WWTPS USING ANAEROBIC DIGESTION**

| STATE | NUMBER OF FACILITIES | % OF TOTAL FACILITIES |
|---|---|---|
| Pennsylvania | 338 | 9.8 |
| California | 239 | 6.9 |
| Ohio | 204 | 5.9 |
| New York | 195 | 5.6 |
| Illinois | 180 | 5.2 |
| Wisconsin | 166 | 4.8 |
| Indiana | 158 | 4.6 |
| Minnesota | 134 | 3.9 |
| Michigan | 133 | 3.9 |
| Texas | 124 | 3.6 |
| *Subtotal* | *1871* | *54.2* |
| Other WWTPs | 1581 | |
| *Total* | *3452* | |

Exhibit 9-4 displays the geographic distribution of the WWTPs in the U.S. that utilize digester gas. As indicated on the map and shown in Exhibit 9-5, ten states account for nearly

72% of the plants that use digester gas with the State of California accounting for just over 21%. Pennsylvania has the largest number of facilities that have anaerobic digester but only 9 of the 338 facilities utilize digester gas.

**EXHIBIT 9-4: GEOGRAPHIC DISTRIBUTION OF WWTPS USING DIGESTER GAS**

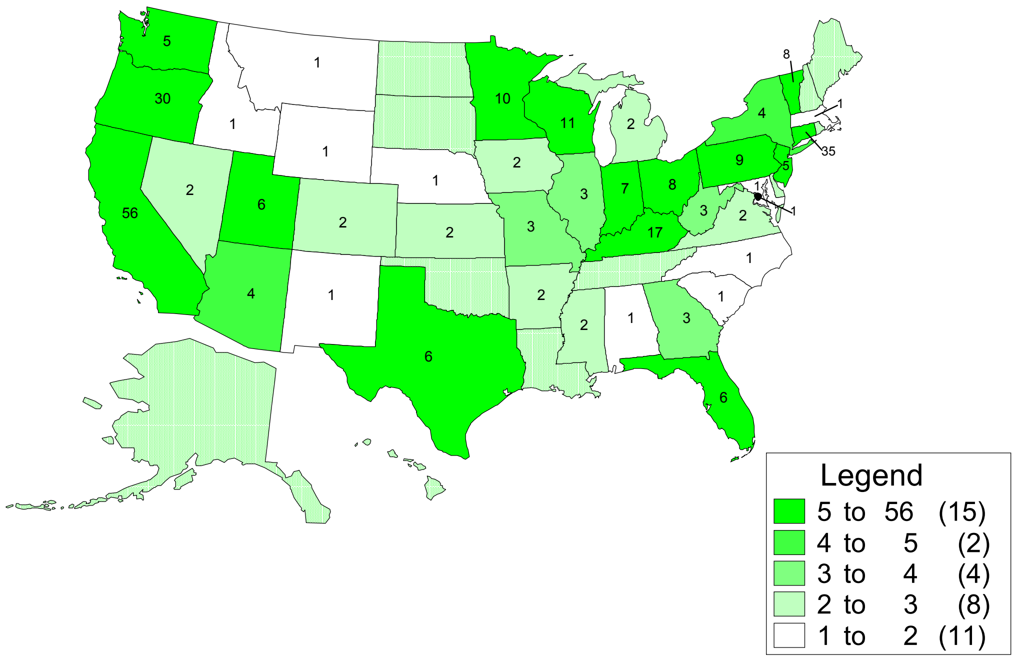



**EXHIBIT 9-5: STATES WITH LARGEST NUMBER OF WWTPS USING DIGESTER GAS**

| STATE | NUMBER OF FACILITIES | % OF TOTAL FACILITIES |
|---|---|---|
| California | 56 | 21.1 |
| Connecticut | 35 | 13.2 |
| Oregon | 30 | 11.3 |
| Kentucky | 17 | 6.4 |
| Wisconsin | 11 | 4.1 |
| Minnesota | 10 | 3.8 |
| Pennsylvania | 9 | 3.4 |
| Vermont | 8 | 3.0 |
| Ohio | 8 | 3.0 |
| Indiana | 7 | 2.6 |
| *Subtotal* | *191* | *71.8* |
| Other WWTPs | 75 | |
| *Total* | *266* | |

### 9.2.3 Characteristics of Typical/Representative WWTPs Using Anaerobic Digestion and Digester Gas

Exhibit 9-6 displays the distribution of the WWTPs with anaerobic digestion in the U.S. by daily design flow. As indicated in the graph, the majority of the facilities (1,580 out of 3,452, or 45.8%) designed for anaerobic digestion are 1 MGD or less. Approximately 1,793 facilities, or 51.9%, are designed to treat between 1 and 50 MGD. The remaining 77 facilities, 2.2%, were designed to treat more than 50 MGD.

**EXHIBIT 9-6: WWTPS WITH ANAEROBIC DIGESTION BY DAILY FLOW IN 2001**

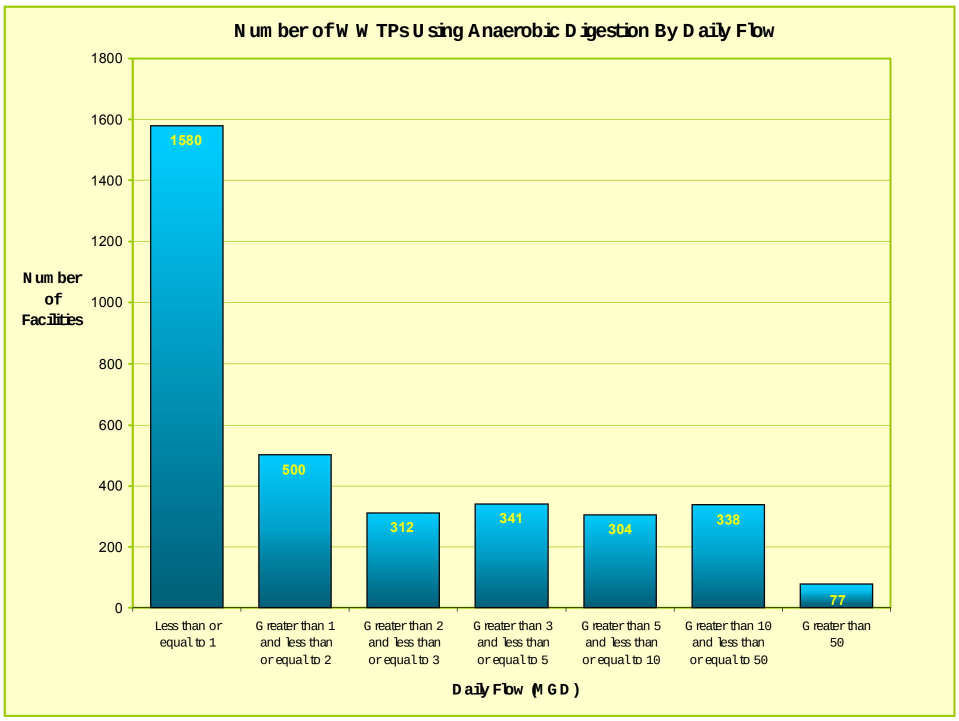
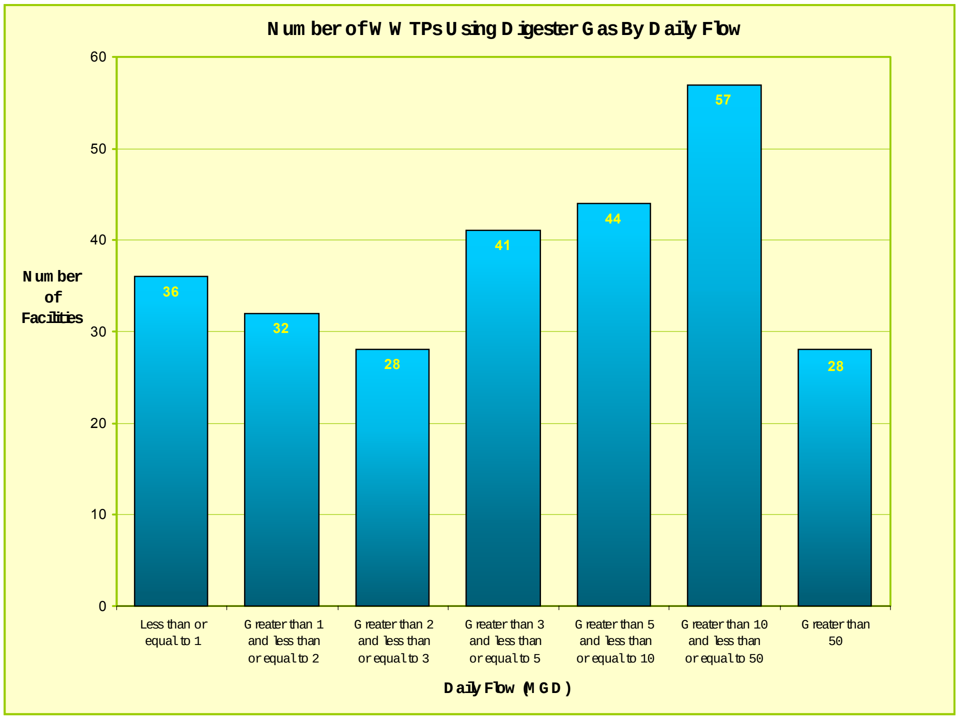



Exhibit 9-7 displays the distribution of the WWTPs that utilize digester gas in the U.S. by daily design flow. As indicated in the graph, the distribution of facilities that use digester gas by daily design flow was roughly even with facilities that treat 10 to 50 MGD having the largest number with 57 of 266 or 21.4 % of the facilities. Exhibits 9-8 and 9-9 present the location of the ten largest WWTPs using digester gas and anaerobic digestion by total daily flow.

### EXHIBIT 9-7: WWTPS USING DIGESTER GAS BY DAILY FLOW




### EXHIBIT 9-8: LOCATION OF TEN LARGEST WWTPS USING DIGESTER GAS BY TOTAL EXISTING DAILY FLOW

| CITY, STATE | TOTAL DAILY FLOW (MGD) |
|---|---|
| Carson, CA | 374 |
| Los Angeles, CA | 360 |
| Washington, DC | 310 |
| Philadelphia, PA | 219 |
| Huntington Beach, CA | 210 |
| Philadelphia, PA | 204 |
| San Diego, CA | 188 |
| Pittsburgh, PA | 164 |
| Baltimore, MD | 160 |
| Dallas, TX | 159 |

**EXHIBIT 9-9: LOCATION OF TEN LARGEST WWTPS USING ANAEROBIC DIGESTION BY TOTAL EXISTING DAILY FLOW**

| CITY | TOTAL DAILY FLOW (MGD) |
|---|---|
| Detroit, MI | 661 |
| Carson, CA | 374 |
| Los Angeles, CA | 360 |
| Boston, MA | 348 |
| Washington, DC | 310 |
| Queens, NY | 271 |
| New York, NY | 250 |
| Chicago, IL | 233 |
| Philadelphia, PA | 219 |
| Palestine, TX | 217 |

### 9.2.4 Energy Usage at Wastewater Treatment Plants

Purchased energy is the largest operating cost of wastewater treatment plants after labor and debt service. The principal form of energy used is purchased electricity, although some larger treatment facilities have developed innovative methods to use biogas generated at the treatment plant to reduce electricity purchases. The principal uses of energy in wastewater treatment are described below:

**Moving wastewater through the collection system and to the treatment process:** This is done with pump stations in the collection system, and may include an influent lift station at the treatment facility. The pumps used for this purpose are almost always powered with electricity. The number of pump stations and power required will depend on the location of the treatment facility, size and topography of the service area, and population distribution across the service area. In rare cases, small communities (i.e., Jerome, Arizona) may be able to convey all wastewater by gravity and not require any pumping. In the case of large systems in flat areas (i.e., Dade County, Florida) hundreds of pump stations are required to deliver wastewater to the treatment facilities. The energy requirement for this purpose is highly variable and site specific.

**Moving wastewater through the treatment process and to the receiving water**: Typical treatment plant design is to have the wastewater flow by gravity between the unit processes beginning at the plant headworks through the final disinfection process. Such systems require no energy for this purpose. Discharge to the receiving water is normally by gravity flow, except for facilities with very long discharge lines, or ocean outfalls where pumping may sometimes be required depending on tide conditions. Most pumps for this purpose are electrically driven, but in some cases one or more pumps may be direct engine driven to ensure reliability in the event of electric power interruption.

**Preliminary (headworks) treatment:** Preliminary treatment removes large debris and grit for the incoming wastewater. Equipment commonly used includes mechanically cleaned bar screens, grit chambers, grit transfer pumps, and grit classifiers. Electric motors are used to operate these devices. Power consumption is relatively low when compared to other processes at a treatment facility.

**Primary Clarification:** Primary clarifiers contain scum collection systems and sludge scraper systems that are mechanically operated. In addition, the clarifier will be equipped with one or more sludge transfer pumps. These pumps remove settled sludge from the clarifier bottom and transfer it to the solids handling system. All these devices are mechanically driven with electric motors. Power consumption is relatively low when compared to other processes at a treatment facility.

**Aeration:** Aeration is required to provide oxygen to activated sludge systems. Aeration systems normally include mechanical surface aerators, or mechanical blowers to feed diffused aeration systems. Both systems use electric powered motors. Aeration represents the largest use of electric power for activated sludge process treatment systems. Trickling filter and activated biofilter plants accomplish aeration by allowing wastewater to flow by gravity down through a static media. Concurrent airflow through the media transfers oxygen to the wastewater where a portion of the wastewater may be recycled back to the biological treatment process by pumping. Electrically driven pumps are always used for these applications.

**Secondary Clarification:** Secondary clarifiers contain the same scum removal and solids scraper mechanisms as primary clarifiers. They are also equipped with pumps to transfer waste biological sludge to the solids handling system. Unlike primary clarifiers, they have a second set of larger pumps used to return the majority of settled solids back to the biological treatment process. This makes power requirements for secondary clarification 3 to 4 times greater than those for primary clarification. Both the clarifier mechanisms and pumps are mechanically driven with electric motors.

**Disinfection:** Where chlorination is used for disinfection almost no power is required. A very small amount may be used for instrumentation, ventilation of areas where chlorine is stored, or pumping chlorine solutions. For systems using Ultraviolet light for disinfection, power costs are far more significant. Electric power is used to provide energy to the UV lamps used in the process. Thus the power requirement is totally dependent on the disinfection system chosen.

**Anaerobic Digestion:** Anaerobic digestion requires the input of both heat, and mechanical energy for mixing. However it also produces energy in the form of biogas (a mixture of methane and carbon dioxide). Typical gas production might be 10-12,000 scf/day of 650 BTU biogas. Many plants burn the biogas to heat the digester. Mechanical mixers or gas lances are used to mix the digester contents. Electric motors provide the energy for this mixing. Many plants use biogas as a boiler fuel to provide heat to anaerobic digesters. An efficient digester is a net producer of energy. Some larger facilities (i.e., San Diego, Los Angeles, Orange County) use a portion of the biogas produced to fuel engine-generators to provide electric power for plant use, or to sell into the local power grid.

**Solids Dewatering:** Solids dewatering is the process by which excess water is removed from digested sludge by some combination of chemical addition and mechanical squeezing. Electric motors are used to add and mix the chemicals, and to provide the mechanical compression.

**Space heating and cooling:** Space heating and cooling may be required for administrative area of treatment facilities depending on geographic location. In extreme northern climates (i.e., Alaska), the treatment units may also be enclosed with heat provided to prevent freezing. Energy use normally consists of electricity for lighting and cooling, and either electricity or fossil fuels for space heating. The energy requirement for these purposes is highly variable and site specific.

To indicate and analyze the energy requirements for each WWTP process, the energy requirements for hypothetical wastewater treatment plants of various sizes were developed based on information presented in EPA's Innovative and Alternative Technology Assessment Manual (February 1980). For the purposes of the analyses, the hypothetical plant consists of preliminary treatment using mechanical bar screens and mechanical grit removal; primary clarification; secondary biological treatment with activated sludge using fine bubble diffusion; secondary clarification; disinfection using chlorination; anaerobic digestion of primary and secondary solids; and belt filtration for solids dewatering. Wastewater pumping to the treatment process is not included. Discharge to the receiving water is assumed to be gravity flow. Energy requirements for a hypothetical WWTP treating 10 MGD is shown in Exhibit 9-10.

**EXHIBIT 9-10: ENERGY REQUIREMENTS FOR HYPOTHETICAL 10 MGD WWTP**

| UNIT PROCESS | | ANNUAL ENERGY REQUIRED |
|---|---|---|
| Preliminary Treatment | | 3,600 (KWh/yr) |
| Primary Sedimentation | | 7,500 (KWh/yr) |
| Aeration for Activated Sludge | | 1,900,000 (KWh/yr) |
| Secondary Clarification | | 30,000 (KWh/yr) |
| Disinfection with Chlorine | | Insignificant |
| Anaerobic Digestion | | |
| | Mixing | 800,000 (KWh/yr) |
| | Heating | 3,650 (Million BTU/yr) |
| Sludge Dewatering | | 20,500 (KWh/yr) |

Currently, WWTPs with anaerobic digesters purchase electricity from the grid, use natural gas, and also utilize the biogas produced by their anaerobic digesters. The biogas has been utilized in many different ways. The primary use has been to reuse the gas to heat the digestors (shown in Exhibit 9-10 as Anaerobic Digestion — Heating). Some wastewater treatment plants recovered the biogas and used it in other ways. Two examples are provided below:

> ***Gloversville-Johnstown Joint Wastewater Treatment Facilities*** in New York use their digester gas to co-generate electrical power using two gas engine generators. The electricity and heat which are produced by the cogeneration system are used in the plant to reduce purchased electricity and natural gas. Electricity produced by the generators is fed into the plant electrical distribution system for use where needed. Heat from the gas engines is recovered and used for heating the digester as well as the energy recovery building (where the two gas generators are housed).
>
> ***Dublin San Ramon District*** in California has reduced purchased power costs by nearly $150,000 per year by taking advantage of its generated biogas using a cogeneration system. It uses a mixture of methane gas from its anaerobic digesters and natural gas to fuel engine-generators. These produce up to 50 percent of the electricity needed to run the plant. In addition, recovered waste heat from the engines keeps the plant building warm in the winter, cools the building in the summer, and heats the solids for processing.

Because the wastewater treatment plants in many cases are recovering the digester gas and using it to heat the digesters, SAIC has not included the energy required for heating the digesters in calculating the total energy requirement for WWTPs.

The energy requirements for the hypothetical WWTP processes was taken directly from EPA's Innovative and Alternative Technology Assessment Manual (February 1980). Using this methodology, SAIC calculated the energy requirements for hypothetical WWTPs of the following sizes: 1 Million Gallons per Day (MGD), 2.5 MGD, 5 MGD, 10 MGD, 20 MGD, 50 MGD, and 100 MGD. The total energy required per year ranges from 270,070 kWh/yr for a 1 MGD plant to 92,262,600 kWh/yr for a 100 MGD plant (Exhibit 9-11). Exhibit 9-12 shows the energy requirements for WWTPs by size (in kWh/yr).

**EXHIBIT 9-11: WASTEWATER TREATMENT PLANT ENERGY REQUIREMENTS (KWH/YR)**

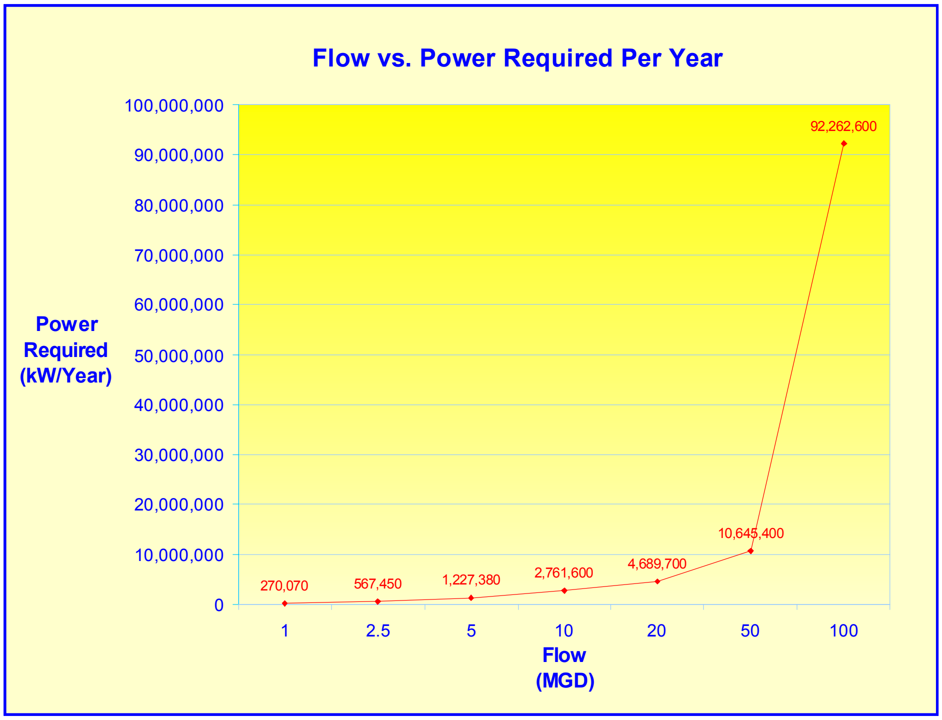
| Component | 1 MGD | 2.5 MGD | 5 MGD | 10 MGD | 20 MGD | 50 MGD | 100 MGD | Source |
|---|---|---|---|---|---|---|---|---|
| Primary Clarification | 1,500 | 2,500 | 4,900 | 7,500 | 10,000 | 35,000 | 60,000 | Fact Sheet 3.1.1 |
| Aeration | 180,000 | 350,000 | 800,000 | 1,900,000 | 3,000,000 | 6,500,000 | 12,000,000 | Fact Sheet 2.1.1 |
| Preliminary Treatment | 1,670 | 2,150 | 2,680 | 3,600 | 4,100 | 5,600 | 6,700 | Fact Sheet 3.1.12 |
| Secondary Clarification | 3,500 | 6,000 | 7,500 | 30,000 | 40,000 | 50,000 | 100,000 | Fact Sheet 3.1.3 |
| Solids Dewatering | 3,400 | 6,800 | 12,300 | 20,500 | 35,600 | 54,800 | 95,900 | Fact Sheet 6.3.3 |
| Anaerobic Digestor | 80,000 | 200,000 | 400,000 | 800,000 | 1,600,000 | 4,000,000 | 8,000,000 | Fact Sheet 6.4.4 |
| Total Power Required per Year | 270,070 | 567,450 | 1,227,380 | 2,761,600 | 4,689,700 | 10,645,400 | 20,262,600 | |
| Power Demand (Average) (kW) | 31 | 65 | 140 | 315 | 535 | 1,215 | 2,313 | |

Fuel cells are sized in kilowatts (kW). In order to determine which size WWTPs could utilize existing fuel cell technology, SAIC also calculated the average power demand by dividing the total power requirements by the total number of hours a WWTP operates in a year (24 hours per day seven days per week or 8,760 hours). The average power demand is shown in the bottom row of Exhibit 9-11. Exhibit 9-13 graphically depicts the total power demand for WWTPs by size in kW. As can be seen in Exhibit 9-13, the average power demand ranges from 31 kW for a 1 MGD wastewater treatment plant to 10,535 kW for a 100 MGD wastewater treatment plant.

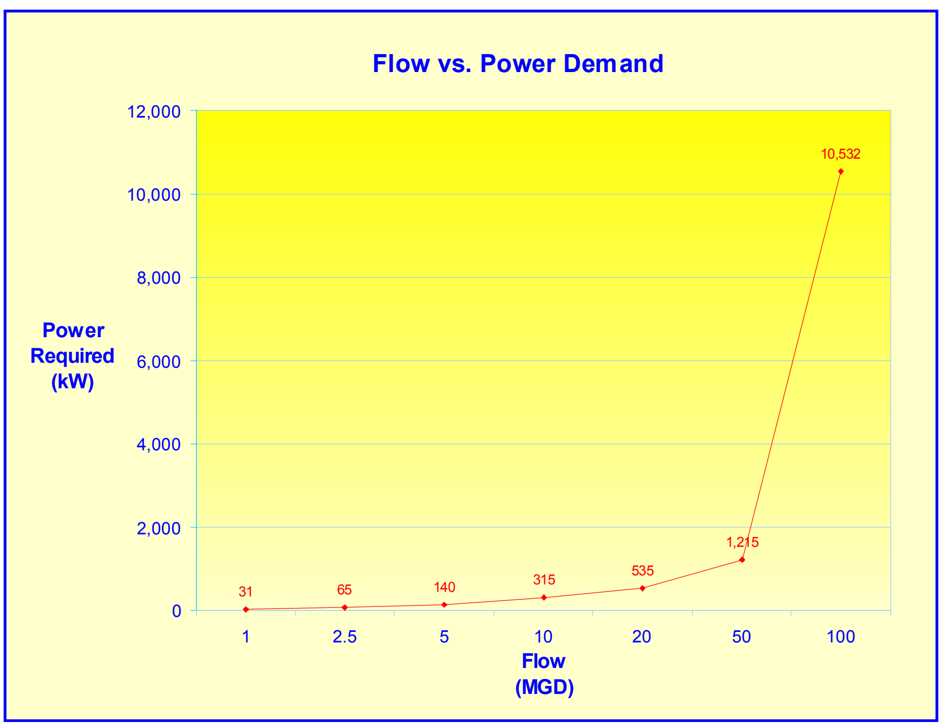
### 9.2.5 Energy Demand Variations at Wastewater Treatment Facilities

The wastewater flows and organic loads to municipal treatment plants are relatively constant from day to day, except during rainfall events. During rain events, flow may rise dramatically and organic loads will increase to a lesser degree. Under dry weather conditions, the flow and load during a 24-hour daily operating cycle will vary significantly. Peak flows will typically occur in the late morning, with the exact time determined by the length of the collection system. A second peak occurs in the early evening, with lesser flows between the two peaks.

### EXHIBIT 9-12: FLOW VS. POWER REQUIREMENTS




### EXHIBIT 9-13: FLOW VS. POWER DEMAND



Lowest flows usually occur between 2 a.m. and 5 a.m. Power consumption at WWTPs increases and decreases with the flow and load. Thus, power consumption is highest in the daytime and lower at night. This difference may be amplified by the fact that most treatment facilities dewater sludge only during the day shift. Unlike wastewater treatment and solids dewatering processes, energy use and biogas production in the anaerobic digestion process is relatively constant throughout the day.

### 9.2.6 Characteristics of Digester Gas

A number of WWTPs were surveyed in EPA's *Demonstration of Fuel Cells to Recover Energy from an Anaerobic Digester Gas- Phase I. Conceptual Design, Preliminary Cost, and Evaluation Study* (EPA/600/SR-95/034, March 1995) to determine the composition of their gas streams. The data indicates that anaerobic digester gas contains approximately 55 to 65 vol % $CH_4$, and 30 to 40 vol % $CO_2$. The gas also contains hydrogen sulfide ($H_2S$) at the parts-per-million level. The results of the gas analysis are shown in Exhibit 9-14.

**EXHIBIT 9-14: TYPICAL DIGESTER GAS COMPOSITIONS (DRY BASIS)**

| | BALTIMORE | NASSAU COUNTY | | NYC DEP | PHILADELPHIA WATER DEPARTMENT | ORANGE COUNTY CALIFORNIA |
|---|---|---|---|---|---|---|
| | BACK RIVER | BAY PARK | CEDAR CREEK | $26_{TH}$ WARD | | |
| *Heating Value HHV, Btu/SCF* | N/M | 670 | N/M | 636 | N/M | N/M |
| *Methane, vol %* | 60.9 | 66.0 | 57.2 | 62.0 | 62.0 | 65.6 |
| *Carbon Dioxide, vol %* | 37.8 | 32.6 | 38.9 | 36.1 | 34.0 | 33.4 |
| *Nitrogen, vol %* | 1.0 | 0.92 | 3.82 | 0.97 | N/M | 1.0 |
| *Oxygen, vol %* | 0.3 (est) | 0.45 | N/M | 0.20 | N/M | 0.03 |
| *Hydrogen Sulfide, ppmv* | 6.0 | 80 | 170** | 100 | <500** | 81 |
| *Halides, ppmv* | <1.0 | ND* | N/M | <1 | N/M | <4 |
| *NMOCs, vol %* | <0.005 | ND* | 0.01** | ND* | N/M | <0.001 |

N/M — Not measured
* Not detected (level of detection not specified)
** Value set from equipment specifications, not from analyses

Most fuel cells used at WWTPs were originally designed to operate on natural gas which is essentially $CH_4$. As described above, typical anaerobic digester gas is not pure methane, and is diluted with $CO_2$. In order for the fuel cell to produce the amount of power it was designed for, a greater volume of anaerobic digester gas must be ducted to it. Steam-driven ejector pumps (that can be powered by a fluid that is steam generated by the fuel cell stack) have achieved the pressure required by the fuel cell. $H_2S$ is another constituent of anaerobic digester gas of concern. If $H_2S$ is fed to the fuel cell, it degrades the catalysts of the fuel cell. Gas cleanup systems have been designed to remove $H_2S$ from digester gas before it reaches the fuel cell, but may introduce a complexity of operation for the wastewater treatment plant operator.

## 9.3 Fuel Cell Market Potential

The fuel cell market potential is determined by matching the average power demand of each WWTP size class (i.e., 1 MGD, 2.5 MGD, 5 MGD) from the industry sector profile (see Section 9.2.3) with the estimated compatibility range of each type of fuel cell (see Chapter 3.0 for an overview of each type of fuel cell). The average power demand is calculated assuming that the electricity is being consumed at a rate of 24 hours a day, 365 days a year, or 8,760 hours per year. It is a measure of the instantaneous power need of a given facility. Exhibit 9-15 highlights the potential market size for different fuel cell technologies in 2010, with Y (Yes) indicating where a particular fuel cell technology is expected to be marketable and N (No) indicating where there is no potential market.

All four types of fuel cell technologies have market potential in the WWTP industry with respect to the projected operating ranges available in 2010 matching the energy demands of the industry. PAFC, PEMFC, and SOFC have the greatest potential market size comprising 4,077 and 4,209 WWTPs (97% and 100% of the WWTP market) while the MCFC potential market is significantly reduced to 999 or 23.7 % of the market.

**EXHIBIT 9-15: FUEL CELL MARKET POTENTIAL IN 2010**

| Plant Size Class (MGD) | Number of Establishments | Average Power Demand (KW) | Fuel Cell Technology & Projected Operating Range for 2010 A | | | |
|---|---|---|---|---|---|---|
| | | | PAFC (50–250 kW) | PEMFC (50–250 kW) | SOFC (50 kW – 5 MW) | MCFC (250 kW – 20 MW) |
| 1 | 2,622 | 31 | Y | Y | Y | N |
| 2.5 | 588 | 65 | Y | Y | Y | N |
| 5 | 411 | 140 | Y | Y | Y | Y |
| 10 | 260 | 315 | Y | Y | Y | Y |
| 20 | 196 | 535 | Y | Y | Y | Y |
| 50 | 71 | 1,215 | N | N | Y | Y |
| 100 | 61 | 2,313 | N | N | Y | Y |
| Potential Market Size: | | | 4,077 | 4,077 | 4,209 | 999 |

A In determining fuel cell size compatibility, the projected operating capabilities for 2010 were expanded by reducing the lower range by 50% and increasing the upper range by 500% to account for the ability to operate the fuel cell at 50% capacity or operate 5 fuel cell systems in parallel.

## 9.4 Technical Assessment

This next section evaluates the technical feasibility of using fuel cell technology within the WWTPs. The technical feasibility of fuel cells entering the WWTP industry sector has been organized into the technical factors presented below. These factors were identified earlier in Chapter 3.0.

- Technology Maturity
- Physical Space Requirements
- Infrastructure Requirements
- Start-up time
- Co-generation Potential
- Fuel Efficiency
- Output Reliability/Consistency
- Fuel Flexibility

Each technical factor is described below with respect to the WWTP industry sector. The relative importance of each factor to the WWTP industry sector is denoted by the number of "ì" to right of the heading. One star (minimum) indicates low importance and three stars (maximum) indicates high importance.

### 9.4.1 Technology Maturity ì ì

As most wastewater treatment facilities perceive power generation to be outside the sphere of their current mission, the maturity of the technology is expected to be a significant factor affecting fuel cell technology acceptance by this industry. However, larger wastewater facilities who have their own internal engineering staff may be more likely to consider a technology with only limited application elsewhere.

### 9.4.2 Physical space requirements ì

The space requirements for PAFC and PEMFC fuel cells are relatively small in comparison to the size of the wastewater treatment process units at the sites where they would be used. At some sites along the California coast, limitations on available space have resulted in steps such as replacing large parking lots with vertical parking structures to make more space available. Across the industry, however, space is usually available for future expansion. In general, space requirements are not expected to be a significant factor in the acceptance of the technology.

### 9.4.3 Infrastructure requirements ì

Acceptance of fuel cell technology is likely to be limited to those plants that utilize anaerobic digestion technology to produce biogas. Thus there is a source of available gas hydrocarbon fuel. Other utility requirements are likely to be available at such sites. The needed infrastructure is not likely to be a significant factor in the acceptance of the technology.

### 9.4.4 Start-up time ì

It is likely that fuel cells installed at wastewater treatment facilities would have to operate continuously in order to minimize the capital cost per unit of power generated. Continuous operation would make start-up time insignificant in the acceptance of the technology in wastewater facilities.

### 9.4.5 Co-generation potential i i

Anaerobic digesters need an external source of heat in order to operate at maximum efficiency. Many facilities currently use the biogas generated in anaerobic digestion as a fuel to provide this heat. The ability of fuel cells to use the heat generated in their operation to return heat to the digester is important in that it will increase the gas available for electric generation. Thus, the potential for co-generation is an important factor in the acceptance of the technology.

### 9.4.6 Fuel efficiency i i

The higher the efficiency in converting fuel (biogas) to heat and electric, the greater the savings in purchased power. To gain acceptance in the industry, fuel efficiency will have to be greater than the boilers currently used for digester heating, or where they are employed, the engine-generators used for power production. Thus, fuel efficiency is an important factor in the acceptance of the technology in wastewater facilities.

### 9.4.7 Output reliability/consistency i

The reliability of the fuel cell units will be a factor in determining the cost of the power generated. Beyond that however, wastewater treatment plants are already equipped with standby generation capabilities to insure reliability. Except for the implications for power generation economics, output reliability/consistency is not considered an important factor in the acceptance of the technology in wastewater facilities.

### 9.4.8 Fuel flexibility i

In addition to the ability to use biogas generated by the wastewater treatment facilities, it is important to be able to switch to an alternative fuel in the event the biogas generation is disrupted. Each of the fuel cell types is expected to be able to utilize biogas and other gas fuel sources available to the facilities. Since fuel flexibility does not represent a discriminator among the fuel cell technologies, it is not likely to be a significant factor in the acceptance of the technology.

## 9.5 Cost Assessment

The purpose of the cost assessment is to determine the financial viability of fuel cells being accepted within the WWTP industry sector. In general, fuel cells will be accepted if the cost of operating and maintaining a fuel cell is equal to or less than the cost associated with purchasing energy from a local supplier; *if*, the fuel cell can improve the reliability (power quality) of electricity for WWTPs.

The cost assessment is divided into two parts: 1) the estimated cost savings of purchasing and operating a fuel cell in the WWTP industry sector in the year 2010; and 2) a qualitative assessment of the relative importance of various economic factors to the WWTP industry sector.

### 9.5.1 Estimated Cost Savings

Information was collected from fuel cell manufacturers to estimate the cost of electricity produced by fuel cells. The cost of electricity includes the installed cost (over a 10-year service life), the fuel purchase cost, and the operation and maintenance costs (O&M). Exhibit 9-16 summarizes the cost of fuel cells for the year 2001 and Exhibit 9-17 summarizes the fuel cell cost projections for the year 2010. Unlike previous sections in this chapter, fuel cell and/or industry market data representing the year 2001 are presented in conjunction with 2010 projections due to the significant level of uncertainty in the 2010 cost estimates. The increased level of uncertainty in the cost projections are based on the lack of maturity and history of fuel cells. The consumption of fuel is estimated at 1,900 $ft^3$/hour of methane as reported by the Energy Research and Development Center (U.S. Army Corps of Engineers) during the U.S. EPA Fuel Cell Workshop held in Cincinnati Ohio, June 26–27, 2001.

**EXHIBIT 9-16: ESTIMATES OF OVERALL ANNUAL FUEL CELL COSTS (2001)**

| | AVERAGE INSTALLED COST ($/kW) | AVERAGE INSTALLED COST (¢/kWh) | INSTALLATION COST OVER 10 YEARS (¢/kWh) | O&M COST (¢/kWh) | FUEL COST (¢/kWh) | TOTAL COST (¢/kWh) |
|---|---|---|---|---|---|---|
| **PAFC** | 2,500 | 28.54 | 2.85 | 1.75 | 5.08 | 9.68 |
| **PEMFC** | 10,000 | 114.16 | 11.42 | 1.75 | 5.08 | 18.25 |
| **SOFC** | 10,000 | 114.16 | 11.42 | 1.5 | 5.08 | 18.00 |
| **MCFC** | 8,000 | 91.32 | 9.13 | 1.5 | 5.08 | 15.71 |

Note: Total cost is the sum of the installed cost over 10 years, O&M costs and fuel costs.

The cost projections for 2010 provided by manufacturers indicate a sharp decline in installed costs, O&M costs, and fuel costs for each fuel cell technology. The combination of these declines results in an overall average decrease of 55% in total costs for all fuel cells between 2001 and 2010.

**EXHIBIT 9-17: ESTIMATES OF OVERALL ANNUAL FUEL CELL COSTS (2010)**

| | AVERAGE INSTALLED COST ($/kW) | AVERAGE INSTALLED COST (¢/kWh) | INSTALLATION COST OVER 10 YEAR (¢/kWh) | O&M COST (¢/kWh) | FUEL COST (¢/kWh) | TOTAL COST (¢/kWh) |
|---|---|---|---|---|---|---|
| **PAFC** | 875 | 9.99 | 1.00 | 1.00 | 4.16 | 6.16 |
| **PEMFC** | 1,200 | 13.70 | 1.37 | 1.00 | 4.16 | 6.53 |
| **SOFC** | 1,250 | 14.27 | 1.43 | 1.00 | 4.16 | 6.59 |
| **MCFC** | 1,250 | 14.27 | 1.43 | 1.00 | 4.16 | 6.59 |

Note: Total cost is the sum of the installed cost over 10 years, O&M costs and fuel costs.

The estimated costs saved by utilizing fuel cell technology is derived by subtracting fuel cell costs from electricity prices when provided by a local electricity supplier. The average annual electricity cost, for the WWTP industry, is 7.0 ¢/kW (estimated from electricity prices for WWTPs in various parts of U.S.). Exhibit 9-18 presents for WWTP's, the financial savings associated with utilizing each type of fuel cell technology in 2001. Installed costs as well as O&M costs have been provided by fuel cell manufacturers. It is on this basis that financial savings are calculated. Exhibit 9-19 presents the cost savings estimated for 2010. Cost savings are only provided for size classes that have a market potential for utilizing fuel cells (see Section 9.3, Fuel Cell Market Potential). Cost savings presented in parentheses indicate negative savings which means that the current fuel cell electricity costs exceed the average annual electricity cost incurred within the WWTP industry sector from local electricity suppliers.

**EXHIBIT 9-18: FINANCIAL SAVINGS FROM FUEL CELL IMPLEMENTATION IN THE WWTP INDUSTRY (2001)**

| SIZE CLASS (MGD) | NUMBER OF ESTABLISHMENTS | COST OF ELECTRICITY (¢/kWh) | PAFC (¢/kWh) | PEMFC (¢/kWh) | SOFC (¢/kWh) | MCFC (¢/kWh) |
|---|---|---|---|---|---|---|
| 2.5 | 482 | 7.0 | N/A | N/A | (11) | N/A |
| 5 | 337 | 7.0 | (3) | (11) | (11) | (9) |
| 10 | 213 | 7.0 | (3) | (11) | (11) | (9) |
| 20 | 161 | 7.0 | (3) | (11) | (11) | (9) |
| 50 | 58 | 7.0 | (3) | (11) | (11) | (9) |
| 100 | 50 | 7.0 | (3) | (11) | (11) | (9) |

N/A: No fuel cell is compatible with that particular size range.

Exhibit 9-18 indicates that a direct implementation of fuel cells in the WWTP industry sector in 2001 is not economically profitable for all fuel cells. Projections provided by manufacturers, as well as energy projections provided by the EIA provide, a more positive economic outlook for implementing fuel cells in the WWTP industry sector for the year 2010 (See Exhibit 9-19).

PAFC technology is the most economically feasible choice for the WWTP industry with a cost savings of 0.8 ¢/kWh. This technology is estimated to provide financial savings equivalent to an annual saving of $34,652/yr. for a WWTP with an output of 10 MGD and $52,469 /yr. for a WWTP with an output of 20 MGD. Extrapolating the cost savings for a PAFC for the estimated market potential of 4,077 establishments within the WWTP industry sector, the potential annual savings for the WWTP industry in 2010 would be over $64.7 million.

**Exhibit 9-19: Financial Savings from Fuel Cell Implementation in the WWTP Industry (2010)**

| Plant Size Class (MGD) | Number of Establishments | Cost of Electricity (¢/kWh) | PAFC (¢/kWh) | PEMFC (¢/kWh) | SOFC (¢/kWh) | MCFC (¢/kWh) |
|---|---|---|---|---|---|---|
| 1 | 2,622 | 7.0 | 0.8 | 0.5 | 0.4 | N/A |
| 2.5 | 588 | 7.0 | 0.8 | 0.5 | 0.4 | N/A |
| 5 | 411 | 7.0 | 0.8 | 0.5 | 0.4 | 0.4 |
| 10 | 260 | 7.0 | 0.8 | 0.5 | 0.4 | 0.4 |
| 20 | 196 | 7.0 | 0.8 | 0.5 | 0.4 | 0.4 |
| 50 | 71 | 7.0 | N/A | N/A | 0.4 | 0.4 |
| 100 | 61 | 7.0 | N/A | N/A | 0.4 | 0.4 |

N/A: Not Applicable — No fuel cell is compatible with that particular size range.

### 9.5.2 Economic Factors on Market Penetration

The economic feasibility of fuel cells entering the WWTP industry sector have been organized into the technical factors presented below. These factors were identified earlier in Chapter 3.0.

- Acquisition Costs
- Annual O&M Costs
- Other Indirect Costs
- Lead Time
- Service Life
- Annual Revenue from the Sale of Electricity
- Possible Energy Tax Credits/Rebates/Grants
- Emissions Credits

Each economic factor is described below with respect to the WWTP industry sector. The relative importance of each factor to the WWTP industry sector is denoted by the number of " ¡ " to right of the heading. One star (minimum) indicates low importance and three stars (maximum) indicates high importance.

**Economic Factors**

#### 9.5.2.1 Acquisition costs ¡ ¡ ¡

For fuel cells to be used at wastewater treatment facilities the unit cost of power they produce must be comparable or less than the cost of power available through other means (i.e., purchased grid power, power generated onsite through the use of engine-generators). As a component of the unit cost per kWh produced, acquisition costs will be an important factor in the acceptance of the technology.

### 9.5.2.2 Annual operation and maintenance costs i i i

As a component of the unit cost per kWh produced, annual operation and maintenance costs will be an important factor in the acceptance of the technology.

### 9.5.2.3 Other indirect costs i i i

As a component of the unit cost per kWh produced, other indirect costs of fuel cells (such as equipment required to clean up/pretreat the biogas) will be an important factor in the acceptance of the technology in wastewater facilities.

### 9.5.2.4 Lead time i

Long lead times for purchase of treatment plant equipment are common and are accepted in the industry. Use of fuel cell technology would be a long term capital improvement that would be permanent in nature. Thus, long lead times would not be a significant factor in the acceptance of the technology in wastewater facilities.

### 9.5.2.5 Service life i

The wastewater industry generally expects pumps and motors to have a useful service life of five to ten years, and other treatment components (i.e., tanks, pipes, structures) to have a service life of 20 to 30 years. Thus fuel cells are expected to have a service life similar to other treatment plant processes. Service life is not expected to be a significant factor with regard to acceptance of the technology in wastewater facilities.

### 9.5.2.6 Annual revenue from the sale of electricity i

Most electricity produced by fuel cells at wastewater treatment plants would be consumed onsite. In general, depending on the treatment processes they employ, primary treatment plants should be able to produce more power than they require with extra power available for sale back to the grid or other off-site uses. Secondary plants should be able to produce about as much power as they require, and advanced (tertiary) plants will probably not be able to produce as much power as they require. Thus, revenue for the sale of electricity may be an important consideration for individual facilities, but will probably not be an important factor for the wastewater industry as a whole.

#### 9.5.2.7 Possible energy tax credits/rebates/grants i i

Because the decision to employ fuel cell technology at wastewater treatment plants will be primarily economically driven, tax credits/rebates/grants could be an important stimulus to developing the acceptance of the technology.

#### 9.5.2.8 Emissions credits i

Since a program for emissions credits for employing fuel cell technology does not currently exist, this is not an important factor in the acceptance of the technology.

### 9.6 Environmental Assessment (Estimate of Greenhouse Gas Emissions from Wastewater Treatment Plants)

According to the Energy Information Administration's (EIA) report *Emissions of Greenhouse Gases in the United States 1999*, domestic and commercial wastewater treatment represented 0.6 percent of all U.S. methane emissions in 1999. By using a default per-capita emissions factor and the U.S. population, EIA estimated the 1999 emissions to be 0.16 million metric tons of methane. EIA estimates that methane emissions from domestic and commercial wastewater treatment have grown by 0.9 percent between 1998 and 1999 and attributes the increase to the U.S. population growing slowly. EIA notes that the estimated methane emissions in 1999 are about 9.3 percent above the 1990 level of 0.15 million metric tons.

An EPA report *Inventory of U.S. Greenhouse Gas Emission Sinks: 1990–1998* also includes estimates for methane emissions from wastewater treatment plants. This report estimated wastewater methane emissions using the default IPCC methodology (IPCC/UNEP/OCED/IEA 1997). The total population for each year was multiplied by a per capita wastewater biochemical oxygen demand (BOD) production rate to determine total wastewater produced. It was then assumed, per capita, 0.05 kilograms of wastewater $BOD_5$ is produced per day and that 15 percent of wastewater $BOD_5$ is anaerobically digested. This proportion of BOD was then multiplied by an emission of 0.22Gg $CH_4$/Gg $BOD_5$. According to this report, the 1998 emissions for methane was 0.9 million metric tons of carbon equivalents.

**EXHIBIT 9-20: EPA AND EIA METHANE EMISSION ESTIMATES**

| YEAR | $CH_4$ EMISSIONS | |
|---|---|---|
| | EPA ESTIMATE (MMTCE) | EIA ESTIMATE (MMT) |
| 1990 | 0.9 | 0.15 |

| | | |
|---|---|---|
| 1991 | 0.9 | |
| 1992 | 0.9 | |
| 1993 | 0.9 | |
| 1994 | 0.9 | |
| 1995 | 0.9 | |
| 1996 | 0.9 | |
| 1997 | 0.9 | |
| 1998 | 0.9 | 0.15 |
| 1999 | | 0.16 |

### 9.6.1 Pollution Avoided ($CO_2$, $SO_2$, $NO_x$)

The avoided pollution is determined by subtracting the pollution emitted by fuel cells if they were used as a power source instead of the power grid from the pollution emitted by the power grid based on the electricity consumption of the WWTP industry sector. The calculation is as follows:

Pollution Avoided = (Pollution Emitted by the Grid) - (Pollution Emitted by Fuel Cells)

The utilization of fuel cells in general reduces emissions as illustrated by the performance specifications of the different types of fuel cells. Fuel cells produce low levels of emissions per kWh of electricity compared to the emissions produced by the power grid per kWh of electricity. The "pollution avoided," as mentioned above, is calculated to determine the environmental advantages of fuel cells as an alternative source of primary power. Exhibit 9-21 illustrates the potential magnitude of pollution avoided if fuel cells were fully implemented (100% of the market potential) within the WWTP industry sector in the years 2001 and 2010. The percentage of pollution avoided when using fuel cells instead of the main grid is also provided for 2001 and 2010 in Exhibit 9-21. Manufacturer's data suggests that for all four types of fuel cells, the amount of pollution generated during operation is virtually the same. This is due to similar types of chemical reactions occurring in each case.

**EXHIBIT 9-21: POTENTIAL POLLUTION AVOIDED IF FUEL CELLS OBTAINED 100% OF THE MARKET POTENTIAL IN THE WWTP INDUSTRY SECTOR IN 2001 AND 2010**

| SIZE CLASS (MGD) | 2001 | | 2010 | |
|---|---|---|---|---|
| | POLLUTION AVOIDED (MILLION lbs.) | PERCENT REDUCTION (%) | POLLUTION AVOIDED (MILLION lbs.) | PERCENT REDUCTION (%) |
| 1 | N/A | N/A | 431 | 28 |

| | | | | |
|---|---|---|---|---|
| 2.5 | 139 | 28 | 169 | 28 |
| 5 | 193 | 28 | 236 | 28 |
| 10 | 375 | 28 | 456 | 28 |
| 20 | 428 | 28 | 524 | 28 |
| 50 | 332 | 28 | 400 | 28 |
| 100 | 876 | 28 | 1,066 | 28 |

Based on the findings in Exhibit 9-21, the pollution avoided as a result of using fuel cells is 28% with respect to air emissions. A comprehensive analysis of competing fuel cell technologies to traditional energy sources (U.S. energy grid) would be necessary to improve the accuracy of the rough-order-of-magnitude assessment conducted.

### 9.6.2 Calculate Fuel Conserved by Using Fuel Cells in 2001 and 2010

In addition to reducing air emissions, the use of fuel cells reduces the amount of fossil fuels used to generate electricity. In 1999, coal generated 51% of electricity, oil generated 3.2%, natural gas generated 15.3%, nuclear generated 19.7%, hydroelectric sources generated 8.3%, and other sources generated 2.4% (EIA) of the total electricity consumed in the U. S. The proportions are very similar for 1998, and it is reasonable to assume that the same proportions apply to the year 2001. It is possible to calculate the quantities of fossil fuel (coal, oil and natural gas) that would not be consumed if fuel cells were to be used instead as a primary source of power. Exhibits 9-22 and 9-23 illustrates the potential magnitude of "displaced fuel," or natural resources conserved if fuel cells were fully implemented (100% of the market potential) within the WWTP industry sector in the years 2001 and 2010.

**EXHIBIT 9-22: NATURAL RESOURCES CONSERVED IN 2001**

| SIZE CLASS (MGD) | NUMBER OF ESTABLISHMENTS | ELECTRICITY USAGE (MWh/yr) | NATURAL RESOURCES CONSERVED | |
|---|---|---|---|---|
| | | | COAL (MILLION lbs.) | OIL (THOUSAND gal.) |
| 2.5 | 482 | 341,497 | 156 | 1,073 |
| 5 | 337 | 475,979 | 217 | 1,495 |
| 10 | 213 | 923,888 | 421 | 2,902 |
| 20 | 161 | 1,054,550 | 480 | 3,312 |
| 50 | 58 | 816,930 | 372 | 2,566 |
| 100 | 50 | 2,158,000 | 983 | 6,778 |

Natural gas being used by the fuel cells is not taken into account in this table.

**EXHIBIT 9-23: NATURAL RESOURCES CONSERVED IN 2010**

| SIZE CLASS (MGD) | NUMBER OF ESTABLISHMENTS | ELECTRICITY USAGE (MWh/yr) | NATURAL RESOURCES CONSERVED | |
|---|---|---|---|---|
| | | | COAL (MILLION lbs.) | OIL (THOUSAND gal.) |
| 1 | 2,622 | 1,061,933 | 468 | 3,335 |
| 2.5 | 588 | 416,283 | 184 | 1,307 |
| 5 | 411 | 580,216 | 256 | 1,822 |
| 10 | 260 | 1,126,214 | 497 | 3,537 |
| 20 | 196 | 1,285,491 | 567 | 4,037 |
| 50 | 71 | 995,833 | 439 | 3,127 |
| 100 | 61 | 2,630,590 | 1,160 | 8,262 |

Natural gas being used by the fuel cells is not taken into account in this table.

### 9.6.3 Environmental Factors for Market Penetration

The key environmental factors associated with fuel cells entering the WWTP industry sector have been organized into the following factors:

- Air Emissions
- Wastewater Production
- Solid Waste Production
- Resource Usage
- Life-Cycle Related Benefits

Each environmental factor is qualitatively described below with respect to the WWTP industry sector. The relative importance of each factor to the WWTP industry sector is denoted by the number of " i " to right of the heading. One star (minimum) indicates low importance and three stars (maximum) indicates high importance.

#### 9.6.3.1 Air emissions i i

The situation at wastewater treatment plants is unique when evaluating air emissions. Several components contribute to this benefit factor: the air emissions associated with the generation/treatment of wastewater on a per capita basis, air emissions associated with the flaring of methane from the anaerobic digester (a significant contributor to pollutant emissions if the biogas is not currently being recovered), and the emissions associated with the purchase of electricity from the grid. Since using fuel cell technology can show a positive reduction in air emissions, this is an important factor in evaluating potential fuel cell use at wastewater treatment plants.

#### 9.6.3.2 Wastewater production i

No significant quantities of wastewater are expected to be generated by any of the technologies. Thus, wastewater generation is not expected to be an important factor in the acceptance of the technology.

#### 9.6.3.3 Solid waste production i

Solid waste generation from PAFC fuel cells generally consists of non-hazardous materials (i.e., filter cartridges), and spent catalysts which can be reclaimed and recycled. Solid waste generation for other types of fuel cells is expected to be similar. Thus, solid waste generation is not expected to be an important factor in the acceptance of the technology.

#### 9.6.3.4 Resource usage i

The principal resource required is a gas hydrocarbon fuel as a feedstock for the fuel cells. Such a feedstock is already present at treatment facilities that utilize anaerobic digestion in the form of biogas. Thus, resource usage is not anticipated to be an important factor with regard to acceptance of the technology.

#### 9.6.3.5 Life-cycle related benefits i

Fuel cell technology is considered to be almost pollution free during its operation (minimal $CO_2$, $SO_x$, $NO_x$, cooling/rinse water, and negligible solid waste). In terms of downstream end-of-life impacts, most manufacturers are reporting that they expect the majority of the fuel cell components to be recyclable (95% by weight according to IFC). Most of the remaining 5% are anticipated to be landfilled with less than 1% being hazardous waste (heavy metal wastes from the cell and/or ancillary fluids). Since very few fuel cell systems have been decommissioned to date, these end-of-life estimates need to be revised as substantiating data become available. In terms of upstream impacts, the life cycle impacts are anticipated to be those common to manufacturing/assembly activities (e.g., structural frame, plumbing, and insulation) including solvents and chemicals from metal processing, paints and coatings, and other assembly/production by-products.

## 9.7 Institutional Considerations

Institutional considerations affecting the marketability of fuel cells in the WWTP industry sector have been organized into institutional considerations/factors presented below. These factors were identified earlier in Chapter 3.0.

- Regulatory Barriers
- Market/Customer Acceptance
- Staff Experience/Training Required

Each institutional factor is described below with respect to the WWTP industry sector. The relative importance of each factor to the WWTP industry sector is denoted by the number of “ i ” to right of the heading. One star (minimum) indicates low importance and three stars (maximum) indicates high importance.

### 9.7.1. Regulatory barriers i

Because fuel cells are an emerging technology, regulatory standards and codes have not yet been developed. As fuel cells gain greater acceptance in this, and other industries, appropriate codes and standards will likely emerge. Thus, regulatory barriers are not anticipated to be an important factor in the acceptance of the technology.

### 9.7.2 Market/customer acceptance i i i

The market/customer acceptance relates to how receptive and motivated a customer is to use fuel cell systems in place of its current sources of power. This particular factor includes reviewing what the customer has invested in providing and maintaining the current power sources (which is linked to the economic factors), the willingness of a customer to utilize cutting-edge innovative technology, and for this particular sector, how the public will value and balance other benefit factors (such as the environmental) in deciding whether to use fuel cell technology.

### 9.7.3 Staff expertise/training needed i i i

While the fuel cells themselves may be relatively simple to operate, the gas conditioning processes needed for both PAFC and PEMFC technologies may require O&M skills that exceed those found at all but the largest wastewater treatment facilities. Maintenance of the inverter equipment needed to convert the direct current produced by fuel cells to the alternating current needed for other treatment plant processes may provide similar challenges. Thus, staff expertise and the training needed will be a significant factor in the acceptance of fuel cell technology in wastewater facilities.

## 9.8 Summary of Fuel Cell Opportunities in the WWTP Industry Sector

The potential market for fuel cell technologies is represented by those wastewater treatment plants which have anaerobic digestion processes. WWTPs that emit anaerobic digester gases (ADG) are prime candidates because the ADG generated can be used as a fuel to the fuel cells, thus decreasing or possibly eliminating the need for outside purchase of natural gas. According to the 1996 Clean Water Needs Survey of the 16,024 facilities in the survey, there are a total of 3,452 wastewater treatment plants (WWTPs) that use anaerobic digestion to treat sewage. Of those plants, a small amount (266) plants currently utilize the digester gas produced from the anaerobic digestion.

Currently WWTPs with anaerobic digesters purchase electricity from the grid, use natural gas, and also utilize the biogas produced by their anaerobic digesters. The biogas has been utilized in many different ways. The primary use has been to reuse the gas to heat the digestors. But the biogas has also been used to co-generate electrical power using two gas engine generators that are used in the plant to reduce purchased electricity and natural gas. In addition, recovered waste heat from the engines keeps the plant building warm in the winter, cools the building in the summer and heats the solids for processing.

All four types of fuel cell technologies have market potential in the WWTP industry with respect to their projected operating ranges in 2010 matching the energy requirements of the industry. PAFC, PEMFC, and SOFC have the greatest potential market size comprising 4,077 and 4,209 WWTPs or 97% and 100% of the WWTP market while the MCFC potential market is significantly reduced to 999 or 23.7 % of the market.

The relative importance of technical, economic, and environmental factors that will influence the marketability of fuel cells in the WWTP industry in 2010 is presented in Exhibit 9-24 and discussed below.

Anaerobic digesters need an external source of heat in order to operate at maximum efficiency. Many facilities currently use the biogas generated in anaerobic digestion as a fuel to provide this heat. The ability of fuel cells to use the heat generated in their operation to return heat to the digester is important in that it will increase the gas available for electric generation. Thus, the potential for co-generation is an important factor in the acceptance of the technology in wastewater facilities.

Fuel efficiency is an important factor in the acceptance of fuel cell technology. The higher the efficiency in converting fuel (biogas) to heat and electric, the greater the savings in purchased power. To gain acceptance in the WWTP industry, the fuel cell's fuel efficiency will have to be greater than the boilers currently used for digester heating, or where they are employed, the engine-generators used for power production.

Purchased energy is the largest operating cost of wastewater treatment plants after labor and debt service. For fuel cells to be used at wastewater treatment facilities the unit cost of power they produce must be comparable or less than the cost of power available through other means (i.e., purchased grid power, power generated onsite through the use of engine-generators). PAFC technology is the most economically feasible choice for the WWTP industry with a cost savings of 0.8 ¢/kWh. The principal uses of energy in wastewater treatment are moving wastewater through the collection system and to the treatment process, moving wastewater through the treatment process and to the

**Exhibit 9-24: Summary of Factors Influencing Marketability of Fuel Cells in the WWTP Industry Sector**

| Technical Factors | |
|---|---|
| Technology maturity | i i |
| Physical space requirements | i |
| Infrastructure requirements | i |
| Start-up time | i |
| Co-generation options | i i |
| Fuel efficiency | i i |
| Output reliability/consistency | i |
| Fuel flexibility | i |
| **Economic Factors** | |
| Acquisition costs (purchase and installation) | i i i |
| Annual operation and maintenance costs | i i i |
| Lead Time | i |
| Other annual indirect costs (e.g., liability, environmental) | i i i |
| Service life | i |
| Annual revenue from sale of output | i |
| Annual business energy tax credits/rebates (Federal, State, local) | i i |
| Emissions credits | i |
| **Environmental Factors** | |
| Air emissions | i i |
| Wastewater releases | i |
| Solid waste (non-hazardous and hazardous) | i |
| Resource usage (water, fuel feedstock) | i |
| Life-Cycle related benefits | i |
| **Institutional Factors** | |
| Regulatory barriers | i |
| Management/customer acceptance | i i i |
| Staff expertise/training required | i i i |

i i i - 3 Stars denote factors critical to marketability in the WWTP sector.

receiving water, preliminary treatment, primary clarification, aeration, secondary clarification, disinfection, anaerobic digestion, solids dewatering and space heating and cooling.

This technology is estimated to provide financial savings equivalent to an annual saving of $34,652 /yr. for a WWTP with an output of 10 MGD and $52,469 /yr. for a WWTP with an output of 20 MGD. Extrapolating the cost savings for a PAFC for the estimated market potential of 4,077 establishments within the WWTP industry sector, the potential annual savings for the WWTP industry in 2010 would be over $64.7 million.

As a component of the unit cost per kWh produced, acquisition costs will be an important factor in the acceptance of the technology. Because the decision to employ fuel cell technology at wastewater treatment plants will be primarily economically driven, tax credits/rebates/grants could be an important stimulus to developing the acceptance of the technology. Annual operation and maintenance costs as well as other indirect costs of fuel cells will be an important factor in the acceptance of the technology in wastewater facilities.

In terms of the economic feasibility, a direct implementation of fuel cells in the WWTP industry sector in 2001 is not economically profitable for all fuel cells. Projections provided by manufacturers, as well as energy projections provided by the EIA, provide a more positive economic outlook for implementing fuel cells in the WWTP industry sector for the year 2010.

In addition, the environmental advantages of producing energy using fuel cells produces a decrease in air emissions of 28%. Also, the natural resources conserved in 2010 as a result of fuel cells include the conservation of 2,222 million lbs. of coal and 814 thousand gallons of oil.

Although the fuel cells are simple to operate, O&M skills may be necessary to maintain the gas conditioning processes needed for both PAFC and PEMFC technologies. Specifically, maintenance of the inverter equipment needed to convert the direct current produced by fuel cells to the alternating current needed for other treatment plant processes may provide similar challenges. Therefore, staff expertise and the training needed will be a significant factor in the acceptance of fuel cell technology in wastewater facilities.

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# Appendix A

**Industry Sector:** Agriculture-Livestock

**Title:** **Freund Farm (Isis Bio-Cell Project)**

**Location:** Freund's Farm Market. East Canaan, CT. 860/824-0650
www.freundsfarmmarket.com

**Fuel Cell Vendor/Partner:** TOR Energy Company. Clinton, CT. 203/265-6959
www.torenergy.com

**Other Partners:** Sponsored in part through Ag-Star, a joint DOE, EPA, and Department of Agriculture voluntary program encouraging the use of methane recovery (biogas) technologies at confined animal feeding operations (CAFOs).

**Fuel Cell Description:** 25 kW high temperature Solid Oxide Fuel Cell (SOFC) processing biogas (i.e., waste methane). The fuel cell's manufacturer reports that with the utilization of the heat by-product the system's operating efficiency is over 80%. Reliability data were not available.

**Status of the Fuel Cell Application:**

Freund Farm, a model farm with 200 milk cows and 150 calves, is the demonstration site for implementing fuel cell technology along with an anaerobic plug flow digester gas process to generate energy from manure (4,000 pounds produced daily). The digester produces 15,000 cubic feet of biogas per day. The fuel cell is intended to process the biogas in order to provide electricity to the farm's facilities. The heat (hot water vapor) will be used to heat the farm's buildings, thus eliminating the need for a hot water boiler. The by-product $CO_2$ exhaust will be used to supplement the atmosphere within 15,000 square feet of greenhouse (located within 250 feet of the digester) where it will revert to oxygen through photosynthesis.

The digester installation occurred between 1997 and 1998. The fuel cell implementation began in the Fall of 2000.

**Problems Encountered:**

None identified by the literature. An e-mail query to the participating farm and fuel cell vendor did not generate a response.

**Benefits/Successes:**

The estimated annual greenhouse gas emissions (i.e., methane) avoided by collecting the waste biogas is 242 metric tons of carbon equivalents.

**Cost Data:**

The installed cost for the biogas digester was $149,000. Costs for the installed fuel cell were not identified.

**References:**

1. Ag-Star Program. www.epa.gov/agstar.
2. Chubb, Lucy. "Farm Looks to Fuel Cells to Help with the Chores". *Environmental News Network*. http://www.enn.com/enn-news-archive/2000/09/09182000/fuelcellfarm_31529.asp?P=2 (9/18/2001 article).
3. Freund's Farm Market. East Canaan, CT. 860/824-0650. www.freundsfarmmarket.com.
4. TOR Energy Company. Clinton, CT. 203/265-6959. www.torenergy.com (various webpages dealing with their fuel cell products and the Isis Bio-Cell Fuel Cell Project).

**Industry Sector:** Educational Services

**Title:** **Liverpool High School Fuel Cell**

**Location:** Liverpool High School, Liverpool, NY. 315/453-1500

**Fuel Cell Vendor/Partner:** International Fuel Cells (IFC), ONSI Corp., South Windsor, CT. 860/727-2200
http://www.internationalfuelcells.com

**Other Partners:** Sponsored in part by the U.S. Department of Defense (DoD) grant from the State of New York.

**Fuel Cell Description:** 200kW

**Status of the Fuel Cell Application:**

As part of a $15 million project to improve energy service to the New York school system, DoD's Climate Change Fuel Cell Program in partnership with the State of New York funded this effort to introduce and demonstrate fuel cell technology at Liverpool High School. The fuel cell generates 200 kW of electricity and 700,000 Btu of usable heat each hour and is expected to reduce emissions of air pollution by 40,000 pounds a year and 1,100 tons of carbon dioxide each year. In addition, the thermal energy generated from the operation of the fuel cell will be used to heat the high school. The partners also envision using the school as an emergency shelter in the event of weather-related power outages or other emergencies since the fuel cell will operate independent of the electrical power grid. The Liverpool High School is the first of 17 schools within the school district that will utilize fuel cell technology. In addition to the economic and environmental advantages of the technology, the partners hope to utilize the fuel cell technology as a teaching tool that will help spur student interest in engineering, science and math.
The fuel cell became operational February 2000.

**Problems Encountered:**

None identified by the literature.

**Benefits/Successes:**

The 200 kW fuel cell is expected to reduce emissions of air pollution by 40,000 pounds a year and 1,100 tons carbon dioxide each year. In addition, the thermal energy generated from the operation of the fuel cell will be used to heat the high school.

**Cost Data:**

No cost data was identified in the literature.

**References:**

1. International Fuel Cells Press Release, *School Gets Cell for Clean 'Juice'; First High School In the Nation to be Equipped with Fuel Cell*, February 17, 2000. http://www.internationalfuelcells.com/news/archive/021700.shtml

**Industry Sector:** Hospitals

**Title:** **South County Hospital**

**Location:** 100 Kenyon Avenue, Wakefield, RI. 401/782-8000

**Fuel Cell Vendor/Partner:** International Fuel Cells, Inc., South Windsor, CT. 860/727-2200 http://www.internationalfuelcells.com

**Other Partners:** Sponsored in part through Department of Defense (DoD)and Rhode Island Renewable Energy Collaborative and administered by the Department of Energy (DOE).

**Fuel Cell Description:** 200 kW PAFC fueled by natural gas.

**Status of the Fuel Cell Application:**

In December 1999, the South County Hospital, located in Wakefield, RI became one of the first hospitals in the New England area to deploy a fuel cell. South County Hospital is a 100-bed facility that provides service to southern Rhode Island. Inpatient and ambulatory services are among the services provided. The hospitals fuel cell unit generates 200kW and is approximately 10 feet by 18 feet. Although the fuel cell operates 24 hours a day, it provides one-third of the hospital's electricity. Therefore, the hospital continues to purchase electricity from Narragansett Electric. In addition, there are three diesel generators on emergency standby. The 200kW unit is expected to prevent the generation of 40,000 pounds of air emissions and 2 million pounds of carbon dioxide each year. In addition to these environmental benefits, the fuel cell provides a reliable source of electricity and a reduction in associated costs for electricity. As a result of the fuel cells operation, the South County Hospital officials expect to reduce associated electricity costs to between $60,000 - 90,000 per year.

**Problems Encountered:**

None identified by the literature.

**Benefits/Successes:**

Expected to prevent the generation of 40,000 pounds of air emissions and 2 million pounds of carbon dioxide each year. Provides continuous 24 hour support for one-third of the hospital.

**Cost Data:**

No data available.

### References:

1. Energy Co-Opportunity (ECO) Industry News, *South County Hospital Leads New England in Fuel Cell Energy*. http://www.energycopportunity.org/news54.cfm (April 6, 2000 article).

**Industry Sector:** Telecommunications Support

**Title:** **Verizon's Zeckendorf Green Power Project**

**Location:** Garden City, Long Island, NY. 516/467-4266

**Fuel Cell Vendor/Partner:** Syska Hennessy. New York, NY. 800/828-1600

**Other Partners:** None identified.

**Fuel Cell Description:** 200kW PAFC that will be fueled by natural gas.

**Status of the Fuel Cell Application:**

Formed from the merger of Bell Atlantic and GTE, Verizon is one of the nation's largest telecommunications companies providing customers with a variety of services ranging from local, and long distance calling to voice, wireless, Internet access and data support systems; all requiring an extremely reliable (99.9%) source of energy. With the help of Syska Hennessy, Verizon is designing a "state-of-the art" energy plant at its Long Island facility. This facility, dubbed the Zeckendorf Green Power Project, is designed to meet the electric and steam needs of the facility.

The energy plant will be located at Verizon's Zeckendorf Central Office Switching Facility, a 300,000+ square foot single story facility with a combination of 80% of offices and 20% switching. This facility alone controls the telecommunications traffic for 4 million residents and 125,000 businesses. The Zeckendorf facility was selected because of the high environmental and economic costs. In addition, the facility has experienced problems with power outages. The Zeckendorf facility currently has three 500 ton electric chillers, two 200 HP boilers for steam heat, and two 2.5 MW combustion turbines that are used for energy stand-by use. The facility's current energy costs are $2 million a year.

In addition to gas turbines and hybrid chillers, the energy plant will be operated using seven 200kW PAFCs that operate on natural gas. The fuel cell is approximately 10'W x 18'L x10'H and will include the fuel processor, cell stack, inverter, transformer, heat recovery, controls and diagnostics. It will also include a supplemental cooling module that is 4'W x 14'L x 4'H. In addition to the PAFCs, the facility will operate with three 700-750 kW natural gas reciprocating engine-generators and two 2,500 kW turbines. The total estimated cost of the project is $17 million. Fixed costs include the purchase of the chillers, engines, fuel cells and construction. The variables identified include reduced energy cost from captured and reused waste heat.

### Problems Encountered:

None identified by the literature as the project is in the planning stage.

### Benefits/Successes:

None identified by the literature as the project is in the planning stage.

### Cost Data:

Total project cost of approximately $17 million.

### References:

1. Syska Hennessy. *Zeckendorf Green Power Project: DG Integration and Telecommunications Facility*, Presentation by Doug Peck (Syska & Hennessy), April 3, 2001.
2. Syska Hennessy. *Verizon, The Zeckendorf Green Power Project-Garden City, Long Island, New York*. http://www.syska.com/market/comm_VERIZON.asp

**Industry Sector:** Wastewater Treatment Plant

**Title:** **King County Wastewater Treatment Plant**

**Location:** Renton, WA. 206/684-2400
http://dnr.metrokc.gov/wtd/southplant/

**Fuel Cell Vendor/Partner:** FuelCell Energy, Danbury, CT./203-825-6000/dferenz@fce.com
http://www.ercc.com/

**Other Partners:** Costs of the project are shared equally by FuelCell Energy and King County through a cooperative grant to King County from U.S. EPA.

**Fuel Cell Description:** 1 MW high temperature, temperature, Molten Carbonate Fuel Cell (MCFC).

**Status of the Fuel Cell Application:**

As part of a two year demonstration project, King County, WA, and FuelCell Energy entered into a cooperative grant through U.S. EPA for $18.8 million to install a 1 MW DFC power plant at the county's wastewater treatment plant (WWTP) located in Renton, WA. The Renton WWTP is a 95 acre plant located south of Seattle. The facility has an average capacity of 108-115 million gallons per day (MGD). The effluent pumps have been upgraded to handle a maximum of 325 MGD of treated wastewater. A typical daily power expenditure for the plant is approximately $7,000. However, during peak rates, this expenditure has reached an expenditure of nearly $137,000. Increasing electricity costs and other considerations drove King County to seek alternatives to the electrical power grid.

The heat produced by the chemical reaction from the fuel cell can be captured and used for the digester and space heating. The Renton WWTP uses an anaerobic (oxygen-free) digester to stabilize solids and reduce pathogens. This process produces methane gas that can be used as a fuel for the fuel cell to generate electricity. WWTPs that typically treat 30 MGD of water can produce 1 MW of electricity. The Renton plant processes approximately 108-115 MGD and can generate 4 MW of electricity. Once online, the WWTP will operate in cogeneration mode and all of the electricity and heat will be consumed by the WWTP. The project was launched January 2001 and construction is expected to begin during the second quarter of 2002. The operation of the plant will begin in the fourth quarter of the same year. The plant is expected to operate for a least one year. The plant specifications and ADG Gas Composition and Air Emissions are presented in Exhibit A-1 below.

**EXHIBIT A-1: KING COUNTY FUEL CELL**

| DFC PLANT SPECIFICATIONS | | AIR EMISSIONS | | ADG GAS COMPOSITION | |
|---|---|---|---|---|---|
| Power Output | 1 MW Net AC | NOx | <0.1 ppmv | Methane | 60% |
| Voltage | 480 Volts | SOx | <0.01 ppmv | Carbon Dioxide | 38% |
| Frequency | 60 Hz | CO | <10 ppmv | Oxygen | 1% |
| Power Quality | Meets IEEE 519 | VOC | <10 ppmv | Nitrogen | 1% |
| Power Output Phase | 3 phase, WYE, 4-Wire | PM10 | Negligible | | |
| Electrical Efficiency | 48.7 LHV | Noise | <60 dB (A) at 100 Feet | | |
| Inherently Safe | Low Gas Volume Fully Contained | | | | |

**Problems Encountered:**

None identified by the literature as the project is not scheduled to begin construction until 2002.

**Benefits/Successes:**

None identified by the literature.

**Cost Data:**

None identified by the literature.

**References:**

1. FuelCell Energy, *Fuel Cell Energy Signs With King County, Washington for Digester/Direct Fuel Cell Energy Project*, January 25, 2001, Danbury, CT. http://www.ercc.com/site/investor/press/releases/2001/01_25_01.html
2. King County, Washington, Department of Natural Resources, Wastewater Treatment Division. *South Treatment Plant, Renton, WA*. http://www.dnr.metrokc.gov/wtd/southplant/
3. King County Washington, Procurement Bulletin #13 - *Energy Efficiency Projects in King County, Renton Treatment Plant-Equipment Upgrades*, June 25, 1998. http://www.metrokc.gov/procure/green/bul13.htmh
4. King County, Washington, Department of Natural Resources Press Release, *Fuel Cell Demonstration Project Seeks to Power South Wastewater Treatment Plant with Facility's Own Methane Gas*. January 25, 2001. http://dnr.metrokc.gov/dnradmin/press/x10125fc.htm

5. "King County Direct Fuel Cell Demonstration Using Digester Gas". Eric Simpkins and Carla Niederhofer, FuelCell Energy and Greg Bush, King County Department of Natural Resources. *U.S. EPA Environmental "Cradle-to-Grave" Analysis of Fuel Cell Applications Conference Proceedings*. August 2001
6. "King County Direct Fuel Cell Project: On-Site Cogeneration Using Advanced Fuel Cell Technology". Eric Simpkins, June 26-27, 2001 (Slide Presentation) in *U.S. EPA Environmental "Cradle-to-Grave" Analysis of Fuel Cell Applications Conference Proceedings*, August 2001.
7. Seattle, Daily Journal of Commerce Online Edition, Fuel Cell Sought to Power Renton Treatment Plant, by Susan Jankowski, April 4, 2000. Http://www.djc.com/news/enviro/11006184.html

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# Appendix B

For each industry sector for which fuel cell technologies were a potential market, additional data such as the pollution avoided, the fuel conserved, and the financial savings associated with using fuel cells were also calculated. These data, although not used to prioritize or down select the most promising sectors, provided extremely valuable and useful information to further characterize the industrial sectors. The methodology used to derive these values and the resulting data tables for the remaining industry sectors is included in this Appendix.

## B.1 Pollution Avoided by Using Fuel Cells

The avoided pollution is determined by subtracting the pollution emitted by fuel cells if they were used as a power source instead of the power grid from the pollution emitted by the power grid based on the electricity consumption of a given industry sector. The calculation is as follows:

Avoided pollution = (Pollution emitted by grid) - (Pollution emitted by fuel cells)

In general, the utilization of fuel cells reduces emissions, as illustrated by the performance specifications of the different types of fuel cells. Fuel cells produce low levels of emissions per kWh of electricity compared to the emissions produced by the power grid per kWh of electricity. The "pollution avoided", as mentioned above, can thus be calculated to give an idea of the environmental advantages presented by the use of fuel cells as an alternative primary source of power. Exhibit B-1 below illustrates the pollution avoided by using fuel cells in 2001 and 2010 in the industry sectors which power demand fits the performance specifications of the fuel cells available. The percentage of pollution avoided when using fuel cells instead of the main electrical grid is also shown for both years.

**EXHIBIT B–1: POLLUTION AVOIDED WHEN USING FUEL CELLS**

| INDUSTRY SECTOR | ESTABLISHMENT SIZE RANGE (NO. OF EMPLOYEES) | NUMBER OF ESTABLISH-MENTS | 2001 | | 2010 | |
|---|---|---|---|---|---|---|
| | | | AVOIDED EMISSIONS (MILLION lbs.) | PERCENT REDUCTION (%) | AVOIDED EMISSIONS (MILLION lbs.) | PERCENT REDUCTION (%) |
| Agriculture-Livestock* | 500-2000+ | 192,616 | 36,978 | 28.00 | 36,978 | 28.00 |
| Banking Facilities | 20-49 | 99 | N/A | N/A | 10 | 28.00 |
| | 50-99 | 50 | 11 | 28.00 | 11 | 28.00 |
| | 100+ | 137 | 223 | 28.00 | 219 | 28.00 |
| Computer/ Data Facilities | 20-49 | 936 | N/A | N/A | 188 | 28.00 |
| | 50-249 | 840 | 374 | 28.00 | 725 | 28.00 |
| | 250-1000+ | 228 | 423 | 28.00 | 819 | 28.00 |
| Educational Services | 1-4 | 31,215 | 675 | 28.00 | 931 | 28.00 |

| Industry Sector | Establishment Size Range (No. of Employees) | Number of Establishments | 2001 | | 2010 | |
|---|---|---|---|---|---|---|
| | | | Avoided Emissions (million lbs.) | Percent Reduction (%) | Avoided Emissions (million lbs.) | Percent Reduction (%) |
| | 5-9 | 10,577 | 801 | 28.00 | 1,104 | 28.00 |
| | 10-19 | 8,864 | 1,438 | 28.00 | 1,983 | 28.00 |
| | 20-49 | 9,057 | 3,429 | 28.00 | 4,727 | 28.00 |
| | 50+ | 6,779 | 3,667 | 28.00 | 5,054 | 28.00 |
| Hospitals | 20-99 | 768 | 268 | 28.00 | 292 | 28.00 |
| | 100-499 | 3,040 | 5,312 | 28.00 | 5,788 | 28.00 |
| | 500+ | 2,816 | 11,481 | 28.00 | 12,511 | 28.00 |
| Landfills | 20-49 | 201 | 25 | 28.00 | 25 | 28.00 |
| | 50-99 | 70 | 19 | 28.00 | 19 | 28.00 |
| | 100-1000+ | 40 | 79 | 28.00 | 79 | 28.00 |
| Military Bases | All | 466 | 5,437 | 28.00 | 5,437 | 28.00 |
| Paper Manufacturing | 1-19 | 12 | 23 | 28.00 | 23 | 28.00 |
| Telecommunications Support | 20-49 | 4005 | N/A | N/A | 1,016 | 28.00 |
| | 50-99 | 1955 | 429 | 28.00 | 1,063 | 28.00 |
| | 100-1000+ | 2155 | 3,467 | 28.00 | 8,592 | 28.00 |
| Traveler Accommodations | 1-4 | 18,589 | 484 | 28.00 | 568 | 28.00 |
| | 5-9 | 6,481 | 591 | 28.00 | 693 | 28.00 |
| | 10-19 | 9,639 | 1,884 | 28.00 | 2,208 | 28.00 |
| | 20-49 | 8,564 | 3,906 | 28.00 | 4,578 | 28.00 |
| | 50+ | 5,689 | 3,707 | 28.00 | 4,344 | 28.00 |
| WWTPs** | 1.0 (MGD) | 2,151 | N/A | N/A | 426 | 28.00 |
| | 2.5 (MGD) | 482 | 137 | 28.00 | 167 | 28.00 |
| | 5 (MGD) | 337 | 190 | 28.00 | 232 | 28.00 |
| | 10 (MGD) | 213 | 369 | 28.00 | 450 | 28.00 |
| | 20 (MGD) | 161 | 421 | 28.00 | 513 | 28.00 |
| | 50 (MGD) | 58 | 323 | 28.00 | 394 | 28.00 |
| | 100 (MGD) | 50 | 853 | 28.00 | 1039 | 28.00 |

* Represents acres of land used for agriculture-livestock.
** Represents wastewater treatment capacity in million gallons per day.
N/A: Not Applicable - No fuel cell is compatible with that particular employee range

## B.2 Fuel Conserved by Using Fuel Cells in 2001 and 2010

In addition to greatly reducing emissions, the use of fuel cells reduces the amount of fossil fuels used to generate electricity. In 1999, coal generated 51% of electricity, oil generated 3.2%, gas generated 15.3%, nuclear generated 19.7%, hydroelectric sources generated 8.3% and other sources generated 2.4% (EIA, 2001) of the total electricity consumed in the United States (U.S.). It is possible to calculate the quantities of fossil fuel (coal, oil and natural gas) that would not be consumed if fuel cells were to be used instead as a primary source of power. Exhibits B-2 and B-3 present a breakdown of the "displaced fuel", or unused fuel for each industry sector where fuel cells can be used as the main source of power instead of the main grid in 2001 and 2010.

**EXHIBIT B-2: FUEL CONSERVED WHEN USING FUEL CELLS IN 2001**

| INDUSTRY SECTOR | ESTABLISHMENT SIZE RANGE (NO. OF EMPLOYEES) | NUMBER OF ESTABLISHMENTS | ELECTRICITY CONSUMPTION (MWh/yr) | FUEL DISPLACED (UNUSED BY EQUIVALENT GRID ELECTRICAL GENERATION) | | |
|---|---|---|---|---|---|---|
| | | | | COAL (MILLION lbs.) | NATURAL GAS (MILLION cu. ft) | OIL (THOUSAND gal.) |
| Agriculture-Livestock* | 500-2000+ | 192,616 | 91,043,383 | 41,466 | 82,389 | 285,962 |
| Banking Facilities | 50-99 | 50 | 27,375 | 12 | 25 | 86 |
| | 100+ | 137 | 550,055 | 251 | 498 | 1,728 |
| Computer/ Data Facilities | 50-249 | 840 | 919,800 | 419 | 832 | 2,889 |
| | 250-1000+ | 228 | 1,040,250 | 474 | 941 | 3,267 |
| Educational Services | 1-4 | 31,215 | 1,662,889 | 757 | 1,505 | 5,223 |
| | 5-9 | 10,577 | 1,972,108 | 898 | 1,785 | 6,194 |
| | 10-19 | 8,864 | 3,541,531 | 1,613 | 3,205 | 11,124 |
| | 20-49 | 9,057 | 8,443,499 | 3,846 | 7,641 | 26,521 |
| | 50+ | 6,779 | 9,028,294 | 4,112 | 8,170 | 28,357 |
| Hospitals | 20-99 | 768 | 660,787 | 301 | 598 | 2,075 |
| | 100-499 | 3,040 | 13,078,080 | 5,955 | 11,832 | 41,067 |
| | 500+ | 2,816 | 28,267,008 | 13,055 | 25,938 | 90,028 |
| Landfills | 20-49 | 201 | 62,011 | 28 | 56 | 195 |
| | 50-99 | 70 | 46,277 | 21 | 42 | 145 |
| | 100-1000+ | 40 | 193,921 | 88 | 175 | 609 |
| Military Bases | All | 466 | 13,382,537 | 6,095 | 12,110 | 42,034 |
| Paper Manufacturing | 1-19 | 12 | 66,013 | 30 | 60 | 207 |
| Telecommunications Support | 50-99 | 1955 | 1,070,363 | 488 | 969 | 3,362 |
| | 100-1000+ | 2155 | 8,652,325 | 3,941 | 7,830 | 21,176 |
| Traveler Accommodations | 1-4 | 18,589 | 1,208,911 | 550 | 1,094 | 3,797 |
| | 5-9 | 6,481 | 1,475,192 | 672 | 1,335 | 4,633 |
| | 10-19 | 9,639 | 4,701,449 | 2,141 | 4,255 | 14,767 |
| | 20-49 | 8,564 | 9,746,601 | 4,439 | 8,820 | 30,613 |

| INDUSTRY SECTOR | ESTABLISH-MENT SIZE RANGE (NO. OF EMPLOYEES) | NUMBER OF ESTABLISH-MENTS | ELECTRICITY CONSUMPTION (MWh/yr) | FUEL DISPLACED (UNUSED BY EQUIVALENT GRID ELECTRICAL GENERATION) | | |
|---|---|---|---|---|---|---|
| | | | | COAL (MILLION lbs.) | NATURAL GAS (MILLION cu. ft) | OIL (THOUSAND gal.) |
| | 50+ | 5,689 | 9,249,418 | 4,213 | 8,370 | 29,052 |
| WWTP** | 2.5 (MGD) | 482 | 341,497 | 155 | 309 | 1,073 |
| | 5 (MGD) | 337 | 475,979 | 217 | 431 | 1,495 |
| | 10 (MGD) | 213 | 923,888 | 421 | 836 | 2,902 |
| | 20 (MGD) | 161 | 1,054,550 | 480 | 954 | 3,312 |
| | 50 (MGD) | 58 | 816,930 | 372 | 739 | 2,566 |
| | 100 (MGD) | 50 | 2,158,000 | 983 | 1,953 | 6,778 |

* Represents acres of land used for agriculture-livestock.
** Represents wastewater treatment capacity in million gallons per day.
Natural gas being used by the fuel cells is not taken into account in this table.

It is important, in the characterization of the industry sectors that generate methane (WWTP, landfills and agriculture), to assess the net difference between methane consumed and methane produced. To calculate the methane consumed, we will use the consumption rate of 1,900 scf/hr for a 200kW and will consider that a fuel will operate 8,760 hours in a year. We will also prorate this consumption rate based on the actual power need of a given facility (i.e., a facility needing half the output of a fuel cell will consume less methane than one needing five fuel cells stringed together). Exhibit B-3 shows, for all three industry sectors, the net amount of methane resulting from the utilization of fuel cells instead of the power grid as the main source of power.

**EXHIBIT B-3: NET METHANE RESULTING FROM FUEL CELL UTILIZATION IN 2001**

| INDUSTRY SECTOR | ESTABLISH-MENT SIZE RANGE (NO. OF EMPLOYEES) | AVERAGE POWER DEMAND (kW) | METHANE PRODUCED (METRIC TON) | METHANE CONSUMED (METRIC TON)* | NET METHANE (METRIC TON)** |
|---|---|---|---|---|---|
| Agriculture-Livestock *** | 500-2000+ | 54 | 19,911,355 | 59 | 19,911,295 |
| Landfills | 20-49 | 35 | 2,769,933 | 39 | 2,769,894 |
| | 50-99 | 75 | 2,067,114 | 83 | 2,067,031 |
| | 100-1000+ | 553 | 8,662,192 | 608 | 8,661,532 |
| WWTP**** | 2.5 (MGD) | 81 | 10,352 | 89 | 10,263 |
| | 5 (MGD) | 161 | 14,476 | 177 | 14,299 |
| | 10 (MGD) | 495 | 18,299 | 544 | 17,755 |
| | 20 (MGD) | 748 | 27,664 | 821 | 26,843 |
| | 50 (MGD) | 1,608 | 24,915 | 1,766 | 23,149 |
| | 100 (MGD) | 4,927 | 42,956 | 5,411 | 37,545 |

*Calculated on the basis of 1900 scf/hr for 8760 hours (one year) of operation for 200kW
**Calculated as "Methane Produced" - "Methane Consumed"
*** Represents acres of land used for agriculture-livestock.
**** Represents wastewater treatment capacity in million gallons per day.

Assuming the same proportions of fossil fuel types used to generate electricity by power plants, the fuel conserved by using fuel cells in 2010 is summarized in Exhibit B-4. This table assumes 100% fuel cell penetration in the applicable markets and sizes presented in columns one and two.

**EXHIBIT B-4: FUEL CONSERVED WHEN USING FUEL CELLS IN 2010**

| INDUSTRY SECTOR | ESTABLISHMENT SIZE RANGE (NO. OF EMPLOYEES) | NUMBER OF ESTABLISHMENTS | ELECTRICITY USAGE (MWh/yr) | FUEL DISPLACED (UNUSED) | | |
|---|---|---|---|---|---|---|
| | | | | COAL (MILLION lbs.) | NATURAL GAS (MILLION cu. ft) | OIL (THOUSAND gal.) |
| Agriculture-Livestock* | 500-2000+ | 192,616 | 91,043,383 | 40,145 | 82,389 | 285,962 |
| Banking Facilities | 20-49 | 99 | 25,295 | 11 | 23 | 79 |
| | 50-99 | 50 | 27,375 | 12 | 25 | 86 |
| | 100+ | 137 | 550,055 | 243 | 498 | 1,728 |
| Computer/ Data Facilities | 20-49 | 936 | 470,404 | 207 | 426 | 1,477 |
| | 50-249 | 840 | 1,809,247 | 798 | 1,637 | 5,682 |
| | 250-1000+ | 228 | 2,046,172 | 902 | 1,852 | 6,427 |
| Educational Services | 1-4 | 10,577 | 2,323,057 | 1,024 | 2,102 | 7,297 |
| | 5-9 | 8,864 | 2,755,034 | 1,214 | 2,493 | 8,653 |
| | 10-19 | 9,057 | 4,947,519 | 2,181 | 4,477 | 15,540 |
| | 20-49 | 6,779 | 11,795,568 | 5,201 | 10,674 | 37,049 |
| | 50+ | 66,492 | 12,612,526 | 5,561 | 11,414 | 39,615 |
| Hospitals | 20-99 | 768 | 729,920 | 322 | 660 | 2,292 |
| | 100-499 | 3040 | 14,446,337 | 6,368 | 13,070 | 45,364 |
| | 500+ | 2816 | 31,224,362 | 13,961 | 28,652 | 99,447 |
| Landfills | 20-49 | 201 | 62,011 | 27 | 56 | 195 |
| | 50-99 | 70 | 46,277 | 20 | 42 | 145 |
| | 100-1000+ | 40 | 193,921 | 86 | 175 | 609 |
| Military Bases | 4,661 | 466 | 13,382,537 | 5,901 | 12,110 | 42,033 |
| Paper Manufacturing | 1-19 | 12 | 66,013 | 29 | 60 | 207 |
| Telecommunications Support | 20-49 | 4005 | 2,535,682 | 1,118 | 2,295 | 7,964 |
| | 50-99 | 1955 | 2,652,358 | 1,169 | 2,400 | 8,331 |
| | 100-1000+ | 2155 | 21,440,461 | 9,454 | 19,402 | 67,343 |
| Traveler Accommodations | 1-4 | 6,481 | 1,416,844 | 625 | 1,282 | 4,450 |
| | 5-9 | 9,639 | 1,728,925 | 762 | 1,565 | 5,430 |
| | 10-19 | 8,564 | 5,510,098 | 2,429 | 4,986 | 17,307 |
| | 20-49 | 5,689 | 11,423,016 | 5,037 | 10,337 | 35,879 |
| | 50+ | 48,962 | 10,840,318 | 4,780 | 9,810 | 34,049 |
| WWTPs** | 1.0 (MGD) | 2151 | 1,061,933 | 468 | 961 | 3,335 |
| | 2.5 (MGD) | 482 | 416,283 | 184 | 377 | 1,307 |
| | 5 (MGD) | 337 | 580,216 | 256 | 525 | 1,822 |
| | 10 (MGD) | 213 | 1,126,214 | 497 | 1,019 | 3,537 |

| INDUSTRY SECTOR | ESTABLISH-MENT SIZE RANGE (NO. OF EMPLOYEES) | NUMBER OF ESTABLISH-MENTS | ELECTRICITY USAGE (MWh/yr) | FUEL DISPLACED (UNUSED) | | |
|---|---|---|---|---|---|---|
| | | | | COAL (MILLION lbs.) | NATURAL GAS (MILLION cu. ft) | OIL (THOUSAND gal.) |
| | 20 (MGD) | 161 | 1,285,491 | 567 | 1,163 | 4,037 |
| | 50 (MGD) | 58 | 995,833 | 439 | 901 | 3,127 |
| | 100 (MGD) | 50 | 2,630,590 | 1,160 | 2,381 | 8,263 |

* Represents acres of land used for agriculture-livestock.
** Represents wastewater treatment capacity in million gallons per day.
Note: Natural gas being used by the fuel cells is not taken into account in this table.

We can also calculate the amount of methane-containing biogas that remains after its consumption by fuel cells as a fuel (i.e., net methane) in WWTP's, landfills and agricultural facilities. Exhibit B-5 shows these amounts."

**EXHIBIT B-5: NET METHANE RESULTING FROM FUEL CELL UTILIZATION IN 2010**

| INDUSTRY SECTOR | ESTABLISH-MENT SIZE RANGE (NO. OF EMPLOYEES) | AVERAGE POWER DEMAND (kW) | BIOGAS PRODUCED (METRIC TON) | METHANE CONSUMED (METRIC TON)* | NET METHANE (METRIC TON)** |
|---|---|---|---|---|---|
| Agriculture-Livestock *** | 500-2000+ | 54 | 19,911,355 | 59 | 19,911,295 |
| Landfills | 20-49 | 35 | 2,769,933 | 39 | 2,769,894 |
| | 50-99 | 75 | 2,067,114 | 83 | 2,067,031 |
| | 100-1000+ | 553 | 8,662,192 | 608 | 8,661,532 |
| WWTPs**** | 1 (MGD) | 56 | 22,527 | 62 | 22,465 |
| | 2.5 (MGD) | 99 | 12,620 | 108 | 12,512 |
| | 5 (MGD) | 196 | 17,647 | 216 | 17,431 |
| | 10 (MGD) | 604 | 22,307 | 663 | 21,644 |
| | 20 (MGD) | 911 | 33,722 | 1001 | 32,721 |
| | 50 (MGD) | 1,960 | 30,371 | 2152 | 28,219 |
| | 100 (MGD) | 6,006 | 52,364 | 6596 | 45,768 |

*Calculated on the basis of 1900 scf/hr for 8760 hours (one year) of operation for 200kW
**Calculated as "Methane Produced" - "Methane Consumed"
*** Represents acres of land used for agriculture-livestock.
**** Represents wastewater treatment capacity in million gallons per day.

## B.3 Financial Savings

A major incentive for decision makers to implement fuel cells within the industry sectors identified in this study is the potential to decrease costs associated with power purchase. This next section presents the financial costs and savings associated with the use of fuel cells in 2001 and 2010. The data gathered from fuel cell manufacturers were used to estimate the cost of electricity produced by fuel cells including fuel purchase and operation and maintenance costs (O&M).

Exhibit B-6 describes these costs. Fuel cells are assumed to have a lifetime of 10 years. The consumption of fuel is assumed to be about 1,900 $ft^3$/hour as reported by the Energy Research and Development Center (U.S. Army Corps of Engineers) during the EPA Fuel Cell Workshop held in Cincinnati Ohio, June 26-27 2001.

**Exhibit B-6: Cost Estimates of Overall Annual Fuel Cell Costs (2001)**

| | AVERAGE INSTALLED COST ($/kW) | AVERAGE INSTALLED COST (¢/kWh) | INSTALLED COST OVER 10 YEARS (¢/kWh) | O&M COST (¢/kWh) | FUEL COST (¢/kWh) | TOTAL COST (¢/kWh) |
|---|---|---|---|---|---|---|
| **PAFC** | 2,500 | 28.54 | 2.85 | 1.75 | 5.08 | 9.68 |
| **PEMFC** | 10,000 | 114.16 | 11.42 | 1.75 | 5.08 | 18.25 |
| **SOFC** | 10,000 | 114.16 | 11.42 | 1.5 | 5.08 | 18.00 |
| **MCFC** | 8,000 | 91.32 | 9.13 | 1.5 | 5.08 | 15.71 |

The cost projections for 2010 provided by manufacturers indicate a sharp decline in installed costs, O&M costs, and fuel costs for each fuel cell technology. The combination of all these declines results in an overall decrease in total costs for all fuel cells between 2001 and 2010 of approximately 70% in average per fuel cell. Exhibit B-7 presents the projected costs for 2010.

**Exhibit B-7: Cost Estimates of Overall Annual Fuel Cell Costs (2010)**

| | AVERAGE INSTALLED COST ($/kW) | AVERAGE INSTALLED COST (¢/kWh) | INSTALLED COST OVER 10 YEARS (¢/kWh) | O&M COST (¢/kWh) | FUEL COST (¢/kWh) | TOTAL COST (¢/kWh) |
|---|---|---|---|---|---|---|
| **PAFC** | 875 | 9.99 | 1.00 | 1.00 | 4.16 | 6.16 |
| **PEMFC** | 1,200 | 13.70 | 1.37 | 1.00 | 4.16 | 6.53 |
| **SOFC** | 1,250 | 14.27 | 1.43 | 1.00 | 4.16 | 6.59 |
| **MCFC** | 1,250 | 14.27 | 1.43 | 1.00 | 4.16 | 6.59 |

The estimated costs saved by utilizing fuel cell technology is derived by subtracting annual fuel cell costs from annual electricity prices when provided by the main power grid. The annual electricity cost is presented in Chapter 4.0 (Exhibit 4-1). Exhibit B-8 presents for each industry sector and by employee range, those sectors that can use fuel cells as their main source of power and the costs savings associated with the specific fuel cell. Employee ranges where fuel cells can not be implemented are not included in this exhibit. The numbers in parentheses indicate negative numbers which means that the current fuel cell electricity costs exceed the power grid costs.

**Exhibit B-8: Costs Saved by Fuel Cell Implementation (2001)**

| INDUSTRY SECTOR | ESTABLISH-MENT SIZE RANGE (NO. OF EMPLOYEES) | NUMBER OF ESTABLISH-MENTS | COST OF ELECTRICITY (¢/kWh) | PAFC (200-250 kW) (cents) | PEMFC (200-250 kW) (cents) | SOFC (50- 5,000 kW) (cents) | MCFC (250-3,000 kW) (cents) |
|---|---|---|---|---|---|---|---|
| Agriculture-Livestock * | 500-2000+ | 192,616 | 7.00 | N/A | N/A | (11) | N/A |
| Banking Facilities | 50-99 | 50 | 7.10 | N/A | N/A | (11) | N/A |
| | 100+ | 137 | 7.10 | (3) | (11) | (11) | (9) |
| Computer/ Data Facilities | 50-249 | 840 | 7.10 | (3) | (11) | (11) | (9) |
| | 250-1000+ | 228 | 7.10 | (3) | (11) | (11) | (9) |
| Educational Services | 5-9 | 10,577 | 8.00 | (2) | (10) | (10) | (8) |
| | 10-19 | 8,864 | 8.00 | (2) | (10) | (10) | (8) |
| | 20-49 | 9,057 | 8.00 | (2) | (10) | (10) | (8) |
| | 50+ | 6,779 | 8.00 | (2) | (10) | (10) | (8) |
| Hospitals | 20-99 | 768 | 6.30 | N/A | N/A | (12) | (9) |
| | 100-499 | 3,040 | 6.30 | (3) | (12) | (12) | (9) |
| | 500+ | 2,816 | 6.30 | (3) | (12) | (12) | (9) |
| Landfills | 20-49 | 201 | 7.80 | (2) | (10) | (10) | (8) |
| | 50-99 | 70 | 7.80 | (2) | (10) | (10) | (8) |
| | 100- 1000+ | 40 | 7.80 | (2) | (10) | (10) | (8) |
| Military Bases | All | 466 | 7.30 | N/A | N/A | (11) | (8) |
| Paper Manufacturing | 1-19 | 12 | 4.10 | N/A | N/A | (14) | (12) |
| Telecommuni-cations Support | 50-99 | 1,955 | 7.10 | N/A | N/A | (11) | N/A |
| | 100-1000+ | 2,155 | 7.10 | (3) | (11) | (11) | (9) |
| Traveler Accommodations | 1-4 | 18,589 | 7.00 | (3) | (11) | (11) | (9) |
| | 5-9 | 6,481 | 7.00 | (3) | (11) | (11) | (9) |
| | 10-19 | 9,639 | 7.00 | (3) | (11) | (11) | (9) |
| | 20-49 | 8,564 | 7.00 | (3) | (11) | (11) | (9) |
| | 50+ | 5,689 | 7.00 | (3) | (11) | (11) | (9) |
| WWTP* | 2.5 (MGD) | 482 | 7.00 | N/A | N/A | (11) | N/A |
| | 5 (MGD) | 337 | 7.00 | (3) | (11) | (11) | (9) |
| | 10 (MGD) | 213 | 7.00 | (3) | (11) | (11) | (9) |
| | 20 (MGD) | 161 | 7.00 | (3) | (11) | (11) | (9) |
| | 50 (MGD) | 58 | 7.00 | (3) | (11) | (11) | (9) |
| | 100 (MGD) | 50 | 7.00 | (3) | (11) | (11) | (9) |

* Represents acres of land used for agriculture-livestock.
** Represents wastewater treatment capacity in million gallons per day.
N/A: Not Applicable - No fuel cell is compatible with that particular employee range

Exhibit B-9 presents for each industry sector and by employee range in 2010, those sectors that can use fuel cells as their main source of power and the costs savings associated with the specific fuel cell. Employee ranges where fuel cells can not be implemented are not included in this exhibit. The numbers in parentheses indicate negative numbers which means that the current fuel cell electricity costs exceed the power grid costs.

**Exhibit B-9: Costs Saved by Fuel Cell Implementation (2010)**

| Industry Sector | Establish-ment Size Range (No. of Employees) | Number of Establish-ments | Cost of Electricity (¢/kWh)* | PAFC (50-250kW) (cents) | PEMFC (50-250kW) (cents) | SOFC (50-5,000kW) (cents) | MCFC (250-20,000kW) (cents) |
|---|---|---|---|---|---|---|---|
| Agriculture-Livestock* | 500-2000+ | 192,616 | 7.0 | 0.8 | 0.5 | 0.4 | N/A |
| Banking Facilities | 20-49 | 99 | 7.1 | 0.9 | 0.6 | N/A | N/A |
| | 50-99 | 50 | 7.1 | 0.9 | 0.6 | 0.5 | N/A |
| | 100+ | 137 | 7.1 | 0.9 | 0.6 | 0.5 | 0.5 |
| Computer/Data Facilities | 20-49 | 1,841 | 7.1 | 0.9 | 0.6 | N/A | N/A |
| | 50-249 | 1,652 | 7.1 | 0.9 | 0.6 | 0.5 | 0.5 |
| | 250-1000+ | 448 | 7.1 | 0.9 | 0.6 | 0.5 | 0.5 |
| Educational Services | 5-9 | 14,776 | 8.0 | 1.8 | 1.5 | 1.4 | 1.4 |
| | 10-19 | 12,383 | 8.0 | 1.8 | 1.5 | 1.4 | 1.4 |
| | 20-49 | 12,653 | 8.0 | 1.8 | 1.5 | 1.4 | 1.4 |
| | 50+ | 9,470 | 8.0 | 1.8 | 1.5 | 1.4 | 1.4 |
| Hospitals | 20-99 | 848 | 6.3 | 0.1 | (0.2) | (0.3) | (0.3) |
| | 100-499 | 3,358 | 6.3 | 0.1 | (0.2) | (0.3) | (0.3) |
| | 500+ | 3,111 | 6.3 | 0.1 | (0.2) | (0.3) | (0.3) |
| Landfills | 20-49 | 201 | 7.8 | 1.6 | 1.3 | 1.2 | 1.2 |
| | 50-99 | 70 | 7.8 | 1.6 | 1.3 | 1.2 | 1.2 |
| | 100-1000+ | 40 | 7.8 | 1.6 | 1.3 | 1.2 | 1.2 |
| Paper Manufacturing | 1-19 | 12 | 4.1 | N/A | N/A | (2.5) | (2.5) |
| Telecommuni-cations Support | 20-49 | 9,924 | 7.1 | 0.9 | 0.6 | N/A | N/A |
| | 50-99 | 4,844 | 7.1 | 0.9 | 0.6 | 0.5 | N/A |
| | 100-1000+ | 5,340 | 7.1 | 0.9 | 0.6 | 0.5 | 0.5 |
| Traveler Accommod-ations | 1-4 | 21,786 | 7.0 | 0.8 | 0.5 | 0.4 | 0.4 |
| | 5-9 | 7,596 | 7.0 | 0.8 | 0.5 | 0.4 | 0.4 |
| | 10-19 | 11,297 | 7.0 | 0.8 | 0.5 | 0.4 | 0.4 |
| | 20-49 | 10,037 | 7.0 | 0.8 | 0.5 | 0.4 | 0.4 |
| | 50+ | 6,668 | 7.0 | 0.8 | 0.5 | 0.4 | 0.4 |
| WWTPs* | 1.0 (MGD) | 2,622 | 7.0 | 0.8 | 0.5 | 0.4 | N/A |
| | 2.5 (MGD) | 588 | 7.0 | 0.8 | 0.5 | 0.4 | N/A |
| | 5 (MGD) | 411 | 7.0 | 0.8 | 0.5 | 0.4 | 0.4 |
| | 10 (MGD) | 260 | 7.0 | 0.8 | 0.5 | 0.4 | 0.4 |
| | 20 (MGD) | 196 | 7.0 | 0.8 | 0.5 | 0.4 | 0.4 |
| | 50 (MGD) | 71 | 7.0 | N/A | N/A | 0.4 | 0.4 |
| | 100 (MGD) | 61 | 7.0 | N/A | N/A | 0.4 | 0.4 |

* Represents acres of land used for agriculture-livestock.
**Represents wastewater treatment capacity in million gallons per day.

N/A: Not Applicable — No fuel cell is compatible with that particular employee range

# Appendix C

## C.1 Exhibits 4-1 and 4-2 Sources and Calculations

The following section summarizes the data sources and calculations that were used in constructing these industry sector summary tables for 2001 and 2010.

### C.1.1 Establishments Size Range

For seven of the Industry Sectors (see list in Exhibit C-1 below), the number of existing facilities and employment size class data for the industry sectors were taken from the County Business Patterns (NAICS) – 1999, published by the U.S. Census Bureau (**http://tier2.census.gov/cbp_naics/index.html**). In it, data were presented under employee ranges (ex: 1-4, 5-9, etc.) and provide the total number of establishments of which the number of employees falls within that range nationwide.

**EXHIBIT C-1: INDUSTRY SECTORS USING CBP DATA**

| Industry Sector | NAICS Code |
|---|---|
| Banking Facilities | 521 & 522320 |
| Computer/Data Facilities | 5142 |
| Educational Services | 611 |
| Landfills | 562212 |
| Logging | 113310 |
| Telecommunications Support | 5133 |
| Traveler Accommodations | 7211 |

For the other industry sectors, various sources as noted below were utilized to define the corresponding establishment range size.

#### C.1.1.1 Agriculture-Livestock

For agriculture, the range provided is based on acres not employees. The number of farms at each size was provided by the following source: 1997 Census of Agriculture – United States Summary and State Data. Volume 1, Geographic Area Series, Part 51. AC97-A-51. United States Department of Agriculture, National Agricultural Statistical Service. Table 8: Land if Farms, Harvested Cropland, and Irrigated Land, by Size of Farm. **http://www.census.gov/prod/ac97/ac97a-51.pdf**

These data were used because they were the most recent data reported by the 1997 Economic Census.

### C.1.1.2 Hospitals

For the number of hospitals and employment size class data, the following source was used: County Business Patterns (NAICS) – 1998 of the U.S. Census Bureau. **http://tier2.census.gov/cbp_naics/index.html**. Since 1998 data from E-GRID were used for hospital emissions, it was determined that the same time period should be used for the number of establishments. Therefore, 1998 County Business Patterns data were used rather than 1999 County Business Patterns data.

### C.1.1.3 Military Installations

For range of establishments, the following source was used: U.S. Military Installations – U.S. Summary by the Department of Defense, September 30, 1995. (**http://defenselink.mil/pubs/installations/**). This source includes the number of military installations (major, minor and other) for the Army, Army Guard, Navy, Air Force, and Marines. This was the most recent data source found. The Army Guard was excluded from the total number of installations. For number of personnel, the following source was used: DoD Active Duty Military Personnel Strength Levels: Fiscal Years 1950-2000 by the Department of Defense Statistical Information Analysis Division (**http://web1.whs.osd.mil/mmid/military/miltop.htm**). This source included numbers of personnel for the Army, Navy, Marine Corps, and Air Force. The number of establishments was based on 1995 data because 1995 personnel data were used.

### C.1.1.4 Paper Manufacturing

For number of establishments, the following four sources were used:

- Paperboard Mills - 1997 Economic Census - Manufacturing - Industry Series. Issued November 1999, EC97M-3221D. U.S. Census Bureau. Table 4: Industry Statistics by Employment Size. **http://www.census.gov/prod/ec97/97m3221d.pdf**
- Pulp Mills - 1997 Economic Census - Manufacturing - Industry Series. Issued November 1999, EC97M-3221A. U.S. Census Bureau. Table 4: Industry Statistics by Employment Size. **http://www.census.gov/prod/ec97/97m3221a.pdf**
- Paper (except Newsprint) Mills - 1997 Economic Census – Manufacturing - Industry Series. Issued November 1999, EC97M-3221B. U.S. Census Bureau. Table 4: Industry Statistics by Employment Size. **http://www.census.gov/prod/ec97/97m3221b.pdf**
- Newsprint Mills - 1997 Economic Census - Manufacturing - Industry Series. Issued November 1999, EC97M-3221C. U.S. Census Bureau. Table 4: Industry Statistics by Employment Size. **http://www.census.gov/prod/ec97/97m3221c.pdf**

Data from all four categories were summed to form the Paper Manufacturing industry sector. These data were used because they were the most recent data reported by the 1997 Economic

Census. They were issued in 1999 as shown in the reference for each document.

#### C.1.1.5 WWTP's

Information was based on conversations with WWTP managers in Ft. Worth, Texas, California, and New York. There was no Country Business Pattern data available for WWTP's.

### C.1.2. Electricity Cost

#### C.1.2.1 Agriculture-Livestock

The electricity cost for the agriculture-livestock industry was derived by dividing the total reported electricity expenditures by the total number of establishments. This is available from the Yearly Expenditure per Establishment in the 1997 Census of Agriculture.

#### C.1.2.2 Banking Facilities, Computer/Data Facilities, Telecommunications Support

For electricity cost, the following source was used: A Look at Commercial Buildings in 1995: Characteristics, Energy Consumption, and Energy Expenditures (ftp://ftp.eia.doe.gov/pub/consumption/commercial/ce95el.pdf) by the U.S. Department of Energy, Energy Information Administration. Table 9: Total Electricity Consumption and Expenditures, 1995 shows the electricity consumption for Offices to be 198 billion kWh and the electricity cost for Offices to be $14,020 million. The data in this report were collected from a sample of 6,639 buildings representing 4.6 million commercial buildings. The Banking Facilities, Computer/Data Facilities, and Telecommunications Support industry sectors were assumed to most closely mimic Offices in the CBECS classifications, hence we assigned them the same electric consumption per employee as the one given for Offices.

Cost per kWh = Total electricity expenditure / Total quantity of electricity purchased
Cost per kWh = $14,020 million / 198 billion kWh
Cost per kWh = $0.071

#### C.1.2.3 Educational Services

For electricity cost, the following source was used: A Look at Commercial Buildings in 1995: Characteristics, Energy Consumption, and Energy Expenditures (ftp://ftp.eia.doe.gov/pub/consumption/commercial/ce95el.pdf) by the U.S. Department of Energy, Energy Information Administration. Schools were assigned the Education electricity consumption rate. Table 9: Total Electricity Consumption and Expenditures, 1995 shows the electricity expenditures for buildings at which the principal activity is education to be $5,168 million. The electricity consumption for the education buildings totals 65 billion kWh. The data in this report were collected from a sample of 6,639 buildings representing 4.6 million commercial buildings.

Cost per kWh = Total electricity expenditure / Total quantity of electricity purchased
Cost per kWh = $5,168 million / 65 billion kWh
Cost per kWh = $0.080

### C.1.2.4 Hospitals

For electricity cost, the following source was used: A Look at Commercial Buildings in 1995: Characteristics, Energy Consumption, and Energy Expenditures (**ftp://ftp.eia.doe.gov/pub/consumption/commercial/ce95el.pdf**) by the U.S. Department of Energy, Energy Information Administration. In the Section on Health Care Buildings, Table 5 presents Electricity Consumption and Cost by Type of Health Care and Size Category. This table shows the electricity cost for inpatient facilities to be $5.91 per hundred kWh (**http://www.eia.doe.gov/emeu/consumptionbriefs/cbecs/pbawebsite/health/health_contents.htm**).

Cost per kWh = ($5.91 / hundred kWh) * (hundred kWh / 100 kWh)
Cost per kWh = $0.0591

### C.1.2.5 Landfills

For electricity cost, the following source was used: A Look at Commercial Buildings in 1995: Characteristics, Energy Consumption, and Energy Expenditures (ftp://ftp.eia.doe.gov/pub/consumption/commercial/ce95el.pdf) by the U.S. Department of Energy, Energy Information Administration. Table 9: Total Electricity Consumption and Expenditures, 1995 shows the electricity expenditures for buildings at which the principal activity is mercantile and service to be $11,655 million. The electricity consumption for the mercantile and service buildings totals 149 billion kWh. The data in this report were collected from a sample of 6,639 buildings representing 4.6 million commercial buildings.

Cost per kWh = Total electricity expenditure / Total quantity of electricity purchased
Cost per kWh = $11,655 million / 149 billion kWh
Cost per kWh = $0.078

The Mercantile and Service category was chosen to represent landfills because it seemed closest to that branch of commercial activity than to any other one.

### C.1.2.6 Logging

Logging - 1997 Economic Census – Manufacturing – Industry Series. Issued November

1999. EC97M-1133A. U.S. Census Bureau. **http://www.census.gov/prod/ec97/97m1133a.pdf**. Table 3: Detailed Statistics by Industry (1997) states that the total cost of purchased electricity was $13,748,000 and that the quantity of electricity purchased for heat and power was 249,361,000 kWh.

Cost per kWh = Total electricity expenditure / Total quantity of electricity purchased
Cost per kWh = $13,748,000 / 249,361,000 kWh
Cost per kWh = $0.055

### C.1.2.7 Military Bases

It was assumed that military bases pay market rate for electricity. Therefore, the national average for electricity cost from EIA was used.

### C.1.2.8 Paper Manufacturing

For electricity cost, the following source was used: Manufacturing Energy Consumption Survey. 1994 MECS Tables and Spreadsheets (**http://www.eia.doe.gov/emeu/mecs/contents.html#mecs94**) by the Energy Information Administration. Total quantity of electricity purchased for Paper and Allied Products was taken from Table A32: Total Quantity of Purchased Energy Sources by Census Region, Census Division, Industry Group, and Selected Industries, 1994 (Estimates in Btu or Physical Units). Electricity (in million kWh) equals 71,514. Total electricity expenditure was taken from Table A36: Total Expenditures for Purchased Energy Sources by Census Region, Census Division, Industry Group, and Selected Industries, 1994 (Estimates in Million Dollars). Electricity for Paper and Allied Products equals $2,951 million.

Cost per kWh = Total electricity expenditure / Total quantity of electricity purchased
Cost per kWh = $2,951 million / 71,514 million kWh
Cost per kWh = $0.041

### C.1.2.9 Traveler Accommodations

For electricity cost, the following source was used: A Look at Commercial Buildings in 1995: Characteristics, Energy Consumption, and Energy Expenditures (ftp://ftp.eia.doe.gov/pub/consumption/commercial/ce95el.pdf) by the U.S. Department of Energy, Energy Information Administration. Hotels were assigned the Lodging electricity consumption rate. Table 9: Total Electricity Consumption and Expenditures, 1995 shows the electricity expenditures for buildings at which the principal activity is lodging to be $3,838 million. The electricity consumption for the lodging buildings totals 55 billion kWh. The data in this report were collected from a sample of 6,639 buildings representing 4.6 million commercial buildings.

Cost per kWh = Total electricity expenditure / Total quantity of electricity purchased

Cost per kWh = \$3,838 million / 55 billion kWh
Cost per kWh = \$0.070

### C.1.2.10 WWTPs

Electricity prices for WWTPs were based on conversations between Bill Hahn (SAIC) and three different WWTP managers (California, Forth Worth-TX and New-York).

## C.1.3 Total Emissions

The following source was used for Total Emissions: The Emissions & Generation Resource Integrated Database (E-GRID2000). This database contains 1998 data. **http://www.epa.gov/airmarkets/egrid/**.

Total emissions were based exclusively on electricity consumption and calculated from national average of typical emissions produced by the grid when producing electricity.

**EXHIBIT C-2: EMISSIONS PRODUCED BY THE ELECTRICAL GRID**

| EMISSIONS PRODUCED (U.S. AVERAGE) | |
|---|---|
| $CO_2$ (lbs./MWh) | 1420.33 |
| $SO_2$ (lbs./MWh) | 7.5 |
| $NO_x$ (lbs./MWh) | 3.55 |

To determine the individual total for $CO_2$, $SO_2$ and $NO_x$, the following equation was used:

Chemical Emissions (million lbs.) = $CO_2$
[Average U.S. Emissions * Electricity Consumption (MWh)] / 1,000,000

To determine Electricity Consumption, see the section title "Total Electricity Consumption."

The Total Emissions number is the sum of the $CO_2$ emissions, $SO_2$ emissions and $NO_x$ emissions.

This methodology was used for Agriculture, Computer/Data Facilities, Educational Services, Landfills, Logging, Military Bases, Telecommunications, and Traveler Accommodations. A slightly different methodology was used for the following industry sectors:, Banking Facilities, Hospitals, Paper Manufacturing and WWTPs.

### C.1.3.1 Banking Facilities and Hospitals

For average number of employees for each employee range and electricity consumption per employee, see the section titled "Total Electricity Consumption."

Avg. electricity consumption per est. (MWh) =

Avg. number of employees per est. * Electricity consumption per emp. (MWh)

Avg. $CO_2$ emissions per est. (lbs.) = Avg. electricity consumption per est. (MWh) * U.S. average $CO_2$ emissions (lbs./MWh)

Avg. $SO_2$ emissions per est. (lbs.) = Avg. electricity consumption per est. (MWh) * U.S. average $SO_2$ emissions (lbs./MWh)

Avg. $NO_x$ emissions per est. (lbs.) = Avg. electricity consumption per est. (MWh) * U.S. average NOx emissions (lbs./MWh)

For total $CO_2$ emissions, the average $CO_2$ emissions were multiplied by the number of establishments. For the source of number of establishments, see the section titled "Range and Number of Establishments."

Total $CO_2$ emissions (lbs.) = Avg. $CO_2$ emissions per est. (lbs.) * Number of est.

Next, the Total Emissions number (in lbs.) was derived by summing the total $CO_2$ emitted, the total $SO_2$ emitted and the total $NO_x$ emitted.

Finally, the total emissions were converted from pounds to million pounds.

Total emissions (millions lbs./year) = Total emissions (lbs./year) * (1 million lbs. / 1,000,000 lbs.)

#### C.1.3.2 Paper Manufacturing

The methodology explained above was conducted for paperboard mills, pulp mills, paper (except newsprint) mills, and newsprint mills. The total emissions for these four categories was summed to determine the total emissions for paper manufacturing.

#### C.1.3.3 WWTPs

The source of emissions data for WWTPs was the 1996 Clean Water Needs Survey.

### C.1.4 Total Electricity Consumption

To determine total electricity consumption (MWh), the energy consumption per employee was derived:

Electricity consumption per employee = (Total electricity consumption)/(Total number of employees)

Then, a representative number of employees was derived for each range of establishments (ex: 7 employees for establishments employing 5 to 9 people).

To determine the total electricity power consumption for all establishments having employees within a given range:

Total electricity consumption for each range of employees = (Midpoint number of employees) * (Electricity consumption per employee) * (Total number of establishments)

### C.1.4.1. Agriculture-Livestock

Source: 1997 Census of Agriculture – United States Summary and State Data. Volume 1, Geographic Area Series, Part 51. AC97-A-51. United States Department of Agriculture, National Agricultural Statistical Service. **http://www.census.gov/prod/ac97/ac97a-51.pdf**.

To determine total electricity consumption (MWh), the energy consumption per acre was derived:

Electricity consumption per acre = (Total electricity consumption) / (Total acreage of farms)

Then, an average farm size (acres) was derived for each range of acres.

To determine the total electricity power consumption for all farms falling within a given size range:

Total electricity consumption for each size range = (Median farm size) * (Electricity consumption per acre) * (Total number of farms)

The median was used because the overall acreage (hence the average) is biased by the farms specializing in crops and necessitating large areas. This report is focused on livestock, not crop-producing farms. The median acreage seemed more representative of what is more likely to be found in any given farm. The source is the 1997 Census of Agriculture - Table 1: County Summary Highlights.

### C.1.4.2 Banking Facilities

The following source was used for electricity consumption per employee: A Look at Commercial Buildings in 1995: Characteristics, Energy Consumption, and Energy Expenditures (**ftp://ftp.eia.doe.gov/pub/consumption/commercial/ce95el.pdf**) by the U.S. Department of Energy, Energy Information Administration. Table 10: Electricity Consumption and Expenditure Intensities, 1995. “Offices.”

The electricity consumption per employee = 7.3 MWh

Then, the remaining calculations noted in C.1.4 above were completed.

#### C.1.4.3 Computer/Data Facilities

The following source was used for electricity consumption per employee: A Look at Commercial Buildings in 1995: Characteristics, Energy Consumption, and Energy Expenditures (**ftp://ftp.eia.doe.gov/pub/consumption/commercial/ce95el.pdf**) by the U.S. Department of Energy, Energy Information Administration. Table 10: Electricity Consumption and Expenditure Intensities, 1995. "Offices."

The electricity consumption per employee = 7.3 MWh

Then, the remaining calculations noted in C.1.4 above were completed.

#### C.1.4.4 Educational Services

The following source was used for total site electricity consumption: A Look at Commercial Buildings in 1995: Characteristics, Energy Consumption, and Energy Expenditures (**ftp://ftp.eia.doe.gov/pub/consumption/commercial/ce95el.pdf**) by the U.S. Department of Energy, Energy Information Administration. Table 9: Total Electricity Consumption and Expenditures, 1995. "Education."

Then, the remaining calculations noted in C.1.4 above were completed.

#### C.1.4.5 Hospitals

Total electricity consumption = Average Electricity Consumption per est. * Number of establishments

[For number of establishments, see the section "Establishments Size Range" and for average electricity consumption per est., see the section on "Total Emissions."]

#### C.1.4.6 Landfills

For total electricity consumption, landfills are assimilated to "service" buildings as classified in the CBECS. The following source was used: A Look at Commercial Buildings in 1995: Characteristics, Energy Consumption, and Energy Expenditures (**ftp://ftp.eia.doe.gov/pub/consumption/commercial/ce95el.pdf**) by the U.S. Department of Energy, Energy Information Administration. Table 10: Electricity Consumption and

Expenditure Intensities, 1995.

Quantity of electricity consumed (MWh) = Total number of employees * Electricity consumed per employee (MWh/emp)
[*For total number of employees, see the section "Establishments Size Range."*]

Electricity consumed per employee (MWh/emp) = Electricity consumption per employee (service) (KWh/emp) / 1000

Electricity consumption per employee (service) = Electricity consumption per sq ft (service) * Average sq. ft per worker (service)

### C.1.4.7 Logging

Source: Logging - 1997 Economic Census – Manufacturing – Industry Series. Issued November 1999. EC97M-1133A. U.S. Census Bureau. **http://www.census.gov/prod/ec97/97m1133a.pdf**. Table 3: Detailed Statistics by Industry (1997).

Total electricity consumption = 249,361 MWh
Total number of employees = 83,203 employees
Therefore, the electricity consumption per employee = 2.9971274 MWh

To complete the remaining calculations noted in C.1.4 above:
For range of employees and total number of establishments within each range, see "Range and Number of Establishments" above.

### C.1.4.8 Military Bases

For total electricity consumption, military bases are assimilated to "service" buildings as classified in the CBECS. The following source was used: A Look at Commercial Buildings in 1995: Characteristics, Energy Consumption, and Energy Expenditures (**ftp://ftp.eia.doe.gov/pub/consumption/commercial/ce95el.pdf**) by the U.S. Department of Energy, Energy Information Administration. Table 10: Electricity Consumption and Expenditure Intensities, 1995.

Average number of personnel per base = Number of employees / Number of establishments
[*See the section on Establishments Size Range.*]

Total square footage per base = Average number of personnel per base * Average square footage per worker (service)

Total Electricity Consumption (MWh) = Electricity consumption per square foot in service (kWh/ft2) * Total square footage per base * Total number of Est. / 1,000

### C.1.4.9 Paper Manufacturing

The sources for the amount of electricity consumed, the amount of electricity generated, and the number of employees are the following:

- Paperboard Mills - 1997 Economic Census - Manufacturing - Industry Series. Issued November 1999, EC97M-3221D. U.S. Census Bureau. Table 3: Detailed Statistics by Industry: 1997. **http://www.census.gov/prod/ec97/97m3221d.pdf**
- Pulp Mills - 1997 Economic Census - Manufacturing - Industry Series. Issued November 1999, EC97M-3221A. U.S. Census Bureau. Table 3: Detailed Statistics by Industry: 1997. **http://www.census.gov/prod/ec97/97m3221a.pdf**
- Paper (except Newsprint) Mills - 1997 Economic Census – Manufacturing - Industry Series. Issued November 1999, EC97M-3221B. U.S. Census Bureau. . Table 3: Detailed Statistics by Industry: 1997. **http://www.census.gov/prod/ec97/97m3221b.pdf**
- Newsprint Mills - 1997 Economic Census - Manufacturing - Industry Series. Issued November 1999, EC97M-3221C. U.S. Census Bureau. Table 3: Detailed Statistics by Industry: 1997. **http://www.census.gov/prod/ec97/97m3221c.pdf**

Next, the electricity consumption and electricity generated per employee were calculated.

Electricity consumption per employee = (Total electricity consumption) / (Total number of employees)

Electricity generated per employee = (Total electricity generated) / (Total number of employees)

Then, an average number of employees was derived for each range of establishments.

Avg. total number of employees = Avg. number of employees per est. * Number of est.

To determine the Quantity of Electricity Purchased for Heat and Power (MWh) and the Quantity of Electricity Generated Less Sold for Heat and Power (MWh), the following equations were used:

Quantity of Electricity Purchased for Heat and Power (MWh) =
Avg. total number of employees * electricity consumption per employee

Quantity of Electricity Generated Less Sold for Heat and Power (MWh) =
Avg. total number of employees * electricity generated per employee

Total Electricity Consumption = Quantity of Electricity Purchased for Heat and Power + Quantity of Electricity Generated Less Sold for Heat and Power

The total electricity consumption for Paperboard Mills, Pulp Mills, Paper (Except Newsprint) Mills, and Newsprint Mills was summed in order to form the total electricity Consumption for Paper Manufacturing.

#### C.1.4.10 Telecommunications Support

The following source was used for electricity consumption per employee: A Look at Commercial Buildings in 1995: Characteristics, Energy Consumption, and Energy Expenditures (**ftp://ftp.eia.doe.gov/pub/consumption/commercial/ce95el.pdf**) by the U.S. Department of Energy, Energy Information Administration. Table 10: Electricity Consumption and Expenditure Intensities, 1995. "Offices."

The electricity consumption per employee = 7.3 MWh

Then, the remaining calculations noted in C.1.4 above were completed.

#### C.1.4.11 Traveler Accommodations

The following source was used for total site electricity consumption: A Look at Commercial Buildings in 1995: Characteristics, Energy Consumption, and Energy Expenditures (**ftp://ftp.eia.doe.gov/pub/consumption/commercial/ce95el.pdf**) by the U.S. Department of Energy, Energy Information Administration. Table 9: Total Electricity Consumption and Expenditures, 1995. "Lodging."

Then, the remaining calculations noted in C.1.4 above were completed.

#### C.1.4.12 WWTPs

The total electricity Consumption was based on conversations with WWTP managers from Ft. Worth, Texas, California, and New York.

### C.1.5 Total Thermal Consumption

To determine the total thermal power consumption per facility (establishment), we extrapolated from CBECS data regarding ratio of thermal to electric consumption for the different industry sectors. We have assimilated several industry sectors to classes given in the Commercial Buildings Energy Consumption Survey (CBECS) and taken the ratio of thermal consumption to energy consumption as follows:

- Offices comprise Banking Facilities, Computer/Data Facilities and Telecommunications Support. For these sectors, 66% of energy consumption is electric and 33% is thermal (a ratio of thermal to electric of 50%).
- Services comprise Agriculture-Livestock, Landfills, Logging and Military Bases. For these sectors, 52% of energy consumption is electric, 48% is thermal (a ratio of thermal to electric of 92%).
- Health Care facilities comprise Hospitals. For this sector, 38% of energy consumption is electric, 62% is thermal (a ratio of thermal to electric of 163%).
- Education facilities comprise Educational Services. For this sector, 36% of energy consumption is electric, 64% is thermal (a ratio of thermal to electric of 178%).
- Lodging facilities comprise Traveler Accommodations. For this sector, 41% of energy consumption is electric, 59% is thermal (a ratio of thermal to electric of 144%)
- The Paper Manufacturing industry sector shows a thermal consumption equal to 2.85 times that of electric consumption (285%).

The following source was used for Offices, Services, Health Care and Schools: A Look at Commercial Buildings in 1995: Characteristics, Energy Consumption, and Energy Expenditures (**ftp://ftp.eia.doe.gov/pub/consumption/commercial/ce95el.pdf**) by the U.S. Department of Energy, Energy Information Administration. Table 1: Total Energy Consumption by Major Fuel, 1995.

% of electric consumption = site electricity energy consumption /
total energy consumption of major fuels * 100

The % of thermal consumption is given by the CBECS (e.g., 33% thermal vs. 66% electric for offices, or a ratio of thermal to electric of 33 / 66 = 0.5). The amount of thermal consumption is then calculated on that basis.

Thermal consumption = Electric consumption X Ratio of Thermal to Electric consumption

### C.1.6 Total Methane (Biogas) Produced

For selected sectors (Agriculture, Landfills and WWTPs), the production of methane was calculated using information from the EPA Global Warming Site: National Emissions-Methane Emissions (**http://www.epa.gov/globalwarming/emissions/national/methane.html**). The total methane emitted nationwide by one industry sector is broken down per establishments of different employee sizes, much like the electricity and thermal consumption.

An MMTCE (Million metric ton of carbon equivalent) factor was given for the three different types of Agriculture products (Enteric fermentation, Manure management, Rice cultivation, Agricultural residue burning). Rice cultivation is very minor (5% of total). This MMTCE factor was translated into methane emissions by the following formula:

$$(MMTCE * 44)/(GWP*12)*1000000$$

44: Molecular mass of $CO_2$
12: Atomic mass of C
GWP: Global Warming Power of methane in 1995 (same as 2001)
1000000: To express the result in metric ton
Source: www.icbe.com/emissions/mmtce.asp

Other industry sectors were assumed to have zero methane emissions.

## C.2 Exhibit 4-3 Fuel Cell Specifications and Estimates of Overall Annual Fuel Cell Costs for 2001 and 2010

The following section summarizes the data sources and calculations that were used in constructing the fuel cell specification costs for four fuel cells. For each of the four types of fuel cells (PAFC, PEMC, MCFC, and SOFC), the total installed cost per kilowatt-hour was calculated. These costs were calculated for both 2001 and 2010 and thus reflect anticipated changes in capital (installed) costs as well as in fuel costs and Operation & Maintenance (O&M) costs over the next 10 years. The specific data and calculations used to characterize each fuel cell technology are described below.

The manufacturers are listed in Chapter 3.0 and are: International Fuel Cells and Siemens Westinghouse. The summary cost values included in Exhibit 4-3 were derived by utilizing the following calculations. These results of these data are presented for the five industry sectors having the greatest potential for fuel cell technology. These data are presented in Exhibits, 5-5, 5-6, 6-7, 6-8, 7-5, 7-6, 8-7, 8-8, 9-16 and 9-17.

### C.2.1 PAFC Costs

For PAFC, the most commercialized type of fuel cell technologies, data do exist to fairly accurately characterize the installed and operating costs.

- The **Average Installed Cost ($/kW)** reported by manufacturers ranges from $2000 to $3000 in 2001 and $750-1000 in 2010.[1,2] Consequently, mid-point values were used to calculate average installed cost.

- The **Average Installed Cost (c/kWh)** was derived from the $/kW reported value by assuming that a fuel cells operates continually (24 hours per day times 365 days per year) for 8,760 hours a year. That number is multiplied by 100 for conversion from dollars to cents.

*Sample Calculation for 2001: (2,500 / 8760) X 100 = 28.54¢/kWh.*

- The **Installation Cost Over 10 years (¢/kWh)** was derived simply by taking a straight line average over an estimated 10 year useful life. If the actual lifespan is proven to be longer, the average cost per year would obviously decrease.

  *Sample Calculation for 2001: 28.54 / 10 = 2.85¢/kWh.*

- The anticipated **O&M Cost (¢/kWh)** (operation and maintenance) reported by manufacturers is the ranges from 1.5-2.0 ¢/kWh in 2001 and 0.5-1.5 ¢/kWh in 2010.[3]

- The **Fuel Cost (¢/kWh)** was calculated from the fuel efficiency of the PAFC in converting natural gas and the national average natural gas price ($5.35 per thousand cubic feet in 2001 and $4.38 per thousand cubic feet in 2010). This assumes an hourly consumption of natural gas of 1,900 cubic feet for a 200 kW output.[4]

  *Sample Calculation for 2001: (5.35/1000) X 1900 = $10.16/hour or 1,016 ¢/hour. Since this is for a 200 kW output, the cost per kWh was then calculated by dividing this price by 200: 1016/200 = 5.08¢/kWh.*

- Consequently, the **Total Cost (¢/kWh)** was then calculated by adding together the Installation Cost Over 10 years, the O&M Cost, and the Fuel Cost

  *Sample Calculation for 2001: 2.85 + 1.75 + 5.08 = 9.69¢/kWh*

### C.2.2 PEMFC Costs

In that PEMFC's have been piloted and field tested, some cost data has been collected from which to make reasonable estimates for 2001 and 2010 total costs. For the most part, manufacturers are anticipating dramatic cost reductions over the next 10 years.

- The **Average Installed Cost ($/kW)** reported by manufacturers is estimated at greater than $10,000 in 2001 and ranges from $900 to 1,500 in 2010.[5,6]

- The **Average Installed Cost (¢/kWh)** was derived from the $/kW reported value by assuming that PEM fuel cells operates continually (24 hours per day times 365 days per year) for 8,760 hours a year. That number is multiplied by 100 for conversion from dollars to cents

  *Sample Calculation for 2001: (10,000 / 8760) X 100 = 114.16¢/*kWh.

- The **Installation Cost Over 10 years (¢/kWh)** was derived by taking a straight line average over an estimated 10 year useful life. If the actual lifespan is proven to be longer, the average cost per year would obviously decrease.

*Sample Calculation for 2001: 114.16 / 10 = 11.41¢/kWh*

- The **O&M Cost (¢/kWh)** reported by manufacturers ranged from 1.5 - 2.0 ¢/kWh in 2001 and 0.5-1.5 ¢/kWh in 2010.[7]

- The **Fuel Cost (¢/kWh)** was calculated by multiplying the national average price of natural gas ($5.35 per thousand cubic feet in 2001 and $4.38 per thousand cubic feet in 2010) by the anticipated conversion efficiency of the PEM fuel cell for converting natural gas to electrical power. Lacking better data, an assumption was used that PEMFCs would convert natural gas at roughly the sample efficiency of PAFC, 1900 cubic feet of natural gas for a 200 kW output.

  *Sample Calculation for 2001: (5.35/1000) X 1900 = $10.16/hour or 1,016 ¢/hour. Since this is for a 200 kW output, the cost per kWh was then calculated by dividing this price by 200, yielding an anticipated fuel cost of 5.08 ¢/kWh.*

- The **Total Cost (¢/kWh)** is calculated by adding up the Installation Cost Over 10 years, the O&M Cost and the Fuel Cost

  *Sample Calculation for 2001: 11.42 + 1.75 + 5.08 = 18.25 ¢/kWh*

### C.2.3 MCFC Costs

- The **Average Installed Cost ($/kW)** given by manufacturers is the average of the both ends of a range given ($8,000 in 2001 and $1,000-1,500 in 2010).

  References: 1. "Fuel Cell Operation on ADG", US EPA Fuel Cell Workshop, June 26, 2001

  2. "Opportunities for Micropower and Fuel Cell/Gas Turbine Hybrid Systems in Industrial Applications," Vol. 1, Arthur D. Little, January 2000)

- The **Average Installed Cost (¢/kWh)** is calculated by assuming that a fuel cell operates (24 X 365 =) 8760 hours a year. That number is multiplied by 100 for conversion from dollars to cents. Calculation: (8,000 / 8760) X 100 = 91.32 for 2001.

- The **Installation Cost Over 10 years (¢/kWh)** is calculated by dividing the Average Installed Cost (¢/kWh) by 10 (number of assumed lifetime of the fuel cell).

  Calculation: 91.32 / 10 = 9.13

- The **O&M Cost (¢/kWh)** (operation and maintenance) given by manufacturers is the average of both ends of a range given (1.0-2 ¢/kWh in 2001 and 0.5-1.5 ¢/kWh in 2010).

  Reference: 1. "Opportunities for Micropower and Fuel Cell/Gas Turbine Hybrid Systems in Industrial Applications," Vol. 1, Arthur D. Little, January 2000)

- The **Fuel Cost (¢/kWh)** is calculated by considering the national average gas price ($5.35 per thousand cubic feet in 2001 and $4.38 per tcf in 2010) and assuming an hourly consumption of natural gas of 1900 cubic feet. For 2001, the calculation is:
  (5.35/1000) X 1900 = $10.16/hour or 1,016 ¢/hour. Since this is for a 200 KW PAFC, the cost per KWh is then calculated by dividing this price by 200: 1016/200 = 5.08 ¢/kWh.

- The **Total Cost (¢/kWh)** is calculated by adding up the Installation Cost Over 10 years, the O&M Cost and the Fuel Cost
  Calculation: 9.13 + 1.5 + 5.08 = 15.71 for 2001

### C.2.3 SOFC Costs

- The **Average Installed Cost ($/kW)** given by manufacturers is the average of the both ends of a range given (>$10,000 in 2001 and 1,000-1,500 in 2010).
  References: 1. "Fuel Cell Operation on ADG", US EPA Fuel Cell Workshop, June 26, 2001
  2. "Opportunities for Micropower and Fuel Cell/Gas Turbine Hybrid Systems in Industrial Applications," Vol. 1, Arthur D. Little, January 2000)

- The **Average Installed Cost (¢/kWh)** is calculated by assuming that a fuel cell operates (24 X 365 =) 8760 hours a year. That number is multiplied by 100 for conversion from dollars to cents. Calculation: (10,000 / 8760) X 100 = 114.16 for 2001.

- The **Installation Cost Over 10 years (¢/kWh)** is calculated by dividing the Average Installed Cost (¢/kWh) by 10 (number of assumed lifetime of the fuel cell).
  Calculation: 114.16 / 10 = 11.41

- The **O&M Cost (¢/kWh)** (operation and maintenance) given by manufacturers is the average of both ends of a range given (1.0-2 ¢/kWh in 2001 and 0.5-1.5 ¢/kWh in 2010).
  Reference: 1. "Opportunities for Micropower and Fuel Cell/Gas Turbine Hybrid Systems in Industrial Applications," Vol. 1, Arthur D. Little, January 2000

- The **Fuel Cost (¢/kWh)** is calculated by considering the national average gas price ($5.35 per thousand cubic feet in 2001 and $4.38 per tcf in 2010) and assuming an hourly consumption of natural gas of 1900 cubic feet. For 2001, the calculation is:
  (5.35/1000) X 1900 = $10.16/hour or 1,016 ¢/hour. Since this is for a 200 KW PAFC, the cost per KWh is then calculated by dividing this price by 200: 1016/200 = 5.08 ¢/kWh.

- The **Total Cost (¢/kWh)** is calculated by adding up the Installation Cost Over 10 years, the O&M Cost and the Fuel Cost
  Calculation: 11.42 + 1.5 + 5.08 = 18.00 for 2001

1. *Fuel Cell Operation on ADG*, US EPA Fuel Cell Workshop, June 26, 2001.

2. *Opportunities for Micropower and Fuel Cell/Gas Turbine Hybrid Systems in Industrial Applications*, Vol. 1, Arthur D. Little, January 2000.

3. *Opportunities for Micropower and Fuel Cell/Gas Turbine Hybrid Systems in Industrial Applications*, Vol. 1, Arthur D. Little, January 2000.

4. As reported by International Fuel Cell in various literature.

5. *Fuel Cell Operation on ADG*, US EPA Fuel Cell Workshop, June 26, 2001.

6. *Opportunities for Micropower and Fuel Cell/Gas Turbine Hybrid Systems in Industrial Applications*, Vol. 1, Arthur D. Little, January 2000.

7. *Opportunities for Micropower and Fuel Cell/Gas Turbine Hybrid Systems in Industrial Applications*, Vol. 1, Arthur D. Little, January 2000.

## C.3 Exhibits 4-4 and 4-5 Ranking of Different Evaluation Factors

The following section summarizes the data sources and calculations that were used in calculating the ranking evaluation factors used to down-select the industry sectors having the greatest fuel cell market potential in 2001 and 2010.

The ranking of the evaluation factors was developed by taking the percentage of the sum total of the specific columns. For example, in the case of number of establishments, the normalized value of 0.847 is derived by dividing the total number of agricultural establishments, 1,046,863 (See Exhibits 4-1 and 4-2) by the total number of establishments for all industrial sectors 1,234,126. The second column (right column) presents the rank of the industry. The Agricultural industry is assigned a rank of 1 since it is the largest contributing sector presenting the number of establishments. The same calculations are performed for Fuel Cell Compatibility, Electricity Costs, Total Emissions, Total Thermal Consumption and Total Biogas Produced. The data sources are presented below.

### C.3.1 Number of Establishments

Total industry sector values for number of establishments from Exhibit 4-1 (2001) and 4-2 (2010) were used.

### C.3.2 Fuel Cell Compatibility (2001 and 2010)

Determining the ability of fuel cells to successfully replace the power grid as the main source of electric power is derived by calculating the Average Power Demand at any given time of a given facility (KW). This power demand is then compared to the power output of a fuel cell. If the average power demand falls between 50% and 500% of the capacity of a fuel cell, then that fuel cell is considered a good alternative for power. It is assumed that a fuel cell can be used for applications requiring only 50% of its power output, and that within a facility, five fuel cells can be linked together to produce five times (500%) the power only one fuel cell would generate.

To calculate Average Power Demand for Computer/Data Facilities, Educational Services, Hospitals Logging and Telecommunications Support Facilities:

Reference time frame (hours) = (24 hours/day) * (365 days/year) = 8760 hours/year
Availability was assumed to be 100%.

Electricity consumption per est. (MWh) = Total electricity consumption / Number of est.

Average power demand (kW) = [Electricity consumption per est. (MWh) / 8760 hours] * [1000 kW / 1 MW]

Fuel cell compatibility equals the numbers of establishments for which a fuel cell could be considered a good alternative for power.

#### C.3.2.1 Banking Facilities, Landfills, Traveler Accommodations and WWTPs

If the average power demand of a given range of employees does not fall with 50% of the lowest end and 500% of the highest end of the output power of fuel cells, it is not compatible. Banks, WWTP's, Hotels and Landfills were determined to have zero compatibility.

#### C.3.2.2 Military Bases

Military Bases have zero fuel cell compatibility because they are very large and no breakdown exists of the different activities taking place on the base. This results in a very large Average Power Demand, considerably higher than what fuel cells can generate.

#### C.3.2.3 Paper Manufacturing

The Average Power Demand (APD) is the weighted average of the quantities used in the four different sub-industries.

Paper Manufacturing APD = ((Pulp Mills APD * Pulp Mills # of est.) + (Newsprint Mills APD * Newsprint Mills # of est.) + (Paper Except Newsprint Mills APD * Paper Except Newsprint

Mills # of est.) + (Paperboard Mills APD * Paperboard Mills # of est.)) / (Pulp Mills # of est. + Newsprint Mills # of est. + Paper Except Newsprint Mills # of est. + Paperboard Mills # of est.)

### C.3.3 Electricity Cost

Total industry sector values for electricity costs from Exhibit 4-1 (2001) and 4-2 (2010) were used.

### C.3.4 Total Emissions

Total industry sector values for emissions from Exhibit 4-1 (2001) and 4-2 (2010) were used.

### C.3.5 Total Electricity Consumption

Total industry sector values for total electricity consumption from Exhibit 4-1 (2001) and 4-2 (2010) were used.

### C.3.6 Total Thermal Consumption

Total industry sector values for total thermal consumption from Exhibit 4-1 (2001) and 4-2 (2010) were used.

### C.3.7 Total Biogas Produced

Total industry sector values for total biogas produced from Exhibit 4-1 (2001) and 4-2 (2010) were used.

### C.3.8 Growth Factors

To create projections for 2010 (Exhibit 4-2), the number of establishments, total emissions, and electricity consumption in Exhibit 4-1 (2001) were increased based on past yearly increases of the numbers of establishments. A multiplier was then developed using the following equation:

X = average year increase based on past data
Y = number of years = 10 years

Multiplier = (1 + x)^10

- For Agriculture-livestock, no increase is assumed. The multiplier for agriculture-livestock is 1.
- For Banking Facilities, Military Bases and Paper Manufacturing, no increase is assumed. The multiplier for these industry sectors is 1.

- For Computer/Data Facilities, average growth between 1998 and 1999 was 7%. The forecast for 2010 is calculated on the same basis. The multiplier for computer/data facilities is 1.967.
- 
- For Educational Services, the average yearly growth percentage was 3.4%. The forecast for 2010 is calculated on the same basis. The multiplier for educational services is 1.397.

- For Hospitals, a 1% increase is assumed. The multiplier for hospitals is 1.104.

- For Landfills, no increase is assumed. The multiplier for landfills is 1.

- For Logging, no increase is assumed. The multiplier for logging is 1.

- For Telecommunications Support, average growth between 1998 and 1999 was 9.5%. The forecast for 2010 is calculated on the same basis. The multiplier for telecommunications support is 2.47.

- For Traveler Accommodations, the average yearly growth percentage was 1.6%. The forecast for 2010 is calculated on the same basis. The multiplier for traveler accommodations is 1.172.

- For WWTPs, consumption is based on forecast values assuming a 2% yearly increase until 2010. The multiplier for WWTPs is 1.219.

## C.4 Pollution Avoided When Using Fuel Cells

The following section summarizes the data sources and calculations that were used in deriving the pollution avoided utilizing fuel cells. The results of these calculations are used in the industry-specific chapters representing the five industry sectors having the greatest potential for fuel cell technology are shown in Exhibits, 5-9, 6-11, 7-9, 8-11, and 9-20. Data for the remaining industry sectors for 2001 and 2010 appear in Appendix B in Exhibit B-1.

Logging was omitted due to lack of fuel cell compatibility and low power needs.

### C.4.1 Range/Employment Size Class

Industry sector ranges from Exhibit 4-1 (2001) and 4-2 (2010) were used. The ranges of employees were determined by comparing their various power needs to the maximum extent of each fuel cell (50-500% capacity).

For Agriculture-Livestock, the range represents acres of land. For WWTP's, the range represents water flow in millions of gallons per day (MGD).

### C.4.2 Number of Establishments

Industry sector values for number of establishments from Exhibit 4-1 (2001) and 4-2 (2010) were used.

### C.4.3 Avoided Emissions

The avoided pollution is determined by subtracting the pollution emitted by fuel cells if they were used as a power source instead of the power grid from the pollution emitted by the power grid based on the electricity consumption of a given industry sector. The calculation is as follows:

Avoided pollution = (Pollution emitted by grid) - (Pollution emitted by fuel cells)

The pollution emitted by the grid for each industry sector is presented in Exhibits 4-1 and 4-2. The pollution emitted by the fuel cells is calculated by using the average emission rate of each fuel cell for $CO_2$, $SO_2$, $NO_x$ is presented in Exhibit C-3.

**EXHIBIT C-3: AVERAGE FUEL CELL EMISSIONS RATE**

| POLLUTANT | PAFC | PEMFC | MCFC | SOFC |
|---|---|---|---|---|
| $CO_2$ | 465 g/kWh | 465 g/kWh | 465 g/kWh | 465 g/kWh |
| $SO_2$ | 0.02 g/kWh | 0.04 g/kWh | 0.001 g/kWh | 0.001 g/kWh |
| $NO_x$ | 0.02 g/kWh | 0.04 g/kWh | 0.0002 g/kWh | 0.006 g/kWh |

### C.4.4 Percent Reduction

(Avoided emissions * 100) / total emissions from the power grid.

## C.5 Fuel Conserved When Using Fuel Cells

The following section summarizes the data sources and calculations that were used in deriving the fuel conserved utilizing fuel cells in 2001 and 2010. The results of these calculations in the industry-specific chapters representing the five industry sectors having the greatest potential for fuel cell technology are shown in Exhibits 5-13, 6-15, 7-13, 8-15, and 9-24. Data for the remaining industry sectors for 2001 and 2010 appear in Appendix B in Exhibit B-1.

### C.5.1 Range/Employment Size Class

Industry sector ranges from Exhibit 4-1 (2001) and 4-2 (2010) were used.

### C.5.2 Number of Establishments

Industry sector number of establishments from Exhibit 4-1 (2001) and 4-2 (2010) were used.

### C.5.3 Electricity Consumption

Industry sector values for electricity consumption from Exhibit 4-1 (2001) and 4-2 (2010) were used.

### C.5.4 Fuel Displaced

The source for the amount of fossil fuels used to generated electricity was the Energy Information Administration (2001).

#### C.5.4.1 Coal Displaced

Amount of Coal Displaced (Million lbs.) = Electricity Consumption (MWh/yr) * 9,386 Btu's per KWh / 1000 * 51 / 100/ (10,510 Btu /lbs.)

9,386 = Heat rate (Btu/KWh) of conventional pulverized coal, this number becomes 9,087 in 2010.
1,000 KWh = 1 MWh
51 = % of electricity in the US generated by coal
10,510 = Heat content of coal (Btu per pound)

#### C.5.4.2 Natural Gas Displaced

Amount of Natural Gas Displaced (Million cubic feet) = Electricity Consumption (MWh/yr) * 933 Btu's per KWh / 1000/ 1,031 Btu/cubic foot

933 = Amount of Btu's per KWh for natural gas
1,000 KWh = 1 MWh
1,031 = Heat rate of NG (Btu/cf)

#### C.5.4.3 Oil Displaced

Amount of Oil Displaced (Thousand gallons) = Electricity Consumption (MWh/yr) * 468 Btu's per KWh / (149,000 Btu/gal)

468 = Amount of Btu's per KWh for oil
1,000 KWh = 1 MWh
3.2 = % of electricity in the US generated by oil
149,000 = Heat content of oil (Btus per gallon)

## C.6 Natural Resources Conserved When Using Fuel Cells

The following section summarizes the data sources and calculations that were used in deriving the natural resources conserved when using fuel cells in 2001 and 2010.

### C.6.1 Range

Industry sector ranges from Exhibit 4-1 (2001) and 4-2 (2010) were used.

### C.6.2 Number of Establishments

Industry sector number of establishments from Exhibit 4-1 (2001) and 4-2 (2010) were used.

### C.6.3 Electricity Consumption

Industry sector values for electricity consumption from Exhibit 4-1 (2001) and 4-2 (2010) were used.

### C.6.4. Natural Resources Conserved

Amount of Natural Gas Conserved (Million cubic feet) = Electricity Consumption (MWh/yr) * 933 Btu's per KWh / 1000/ 1,031 Btu/cubic foot

933 = Amount of Btu's per KWh for natural gas
1000 KWh = 1 MWh
1031 = Heat rate of NG (Btu/cf)

#### C.6.4.1 Coal

Amount of Coal Conserved (Million lbs.) = Electricity Consumption (MWh/yr) * 9,386 Btu's per KWh / 1000 * 51 / 100/ (10, 510 Btu/lbs.)

9,386 = Heat rate (Btu/KWh) of conventional pulverized coal, this number becomes 9,087 in 2010.
1,000 KWh = 1 MWh
51 = % of electricity in the US generated by coal
10,510 = Heat content of coal (Btu per pound)

### C.6.4.2. Oil

Amount of Oil Conserved (Thousand gallons) = Electricity Consumption (MWh/yr) * 468 Btu's per KWh / (149,000 Btu/gal)

468 = Amount of Btu's per KWh for oil
1000 KWh = 1 MWh
3.2 = % of electricity in the US generated by oil
149,000 = Heat content of oil (Btus per gallon)

## C.7 Actual Fuel Consumed/Conserved When Using Fuel Cells

### C.7.1 Natural Gas Consumed

This is the total amount of natural gas consumed by a given facility calculated on the basis of 1,900 $ft^3$/hour for 8,760 hours in a year (24 X 365). Since this consumption rate of 1,900 $ft^3$/hour is that of a 200 kW PAFC, the consumption rate is prorated by the Average Power Demand. Since this calculation is relevant only to a single establishment, a multiplier corresponding to the total number of establishments is introduced:

Natural Gas Consumed = 1,900 X 8,760 X (Number of establishments) X (200 / Average Power Demand)

### C.7.2 Natural Gas Displaced

Amount of Natural Gas Displaced (Million cubic feet) = Electricity Consumption (MWh/yr) * 933 Btu's per KWh / 1000/ (1,031 Btu/cf)

933 = Amount of Btu's per KWh for natural gas
1000 KWh = 1 MWh
1031 = Heat rate of NG (Btu per cubic foot)

### C.7.3. Net Natural Gas

This is the difference between the Natural Gas consumed and the Natural Gas Displaced.

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